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Ministry of Energy, Mines
and Petroleum Resources

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Geological Survey Branch

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A summary of Field Activities and Current Research

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January 1987

FOREWORD

This is the twelfth edition of *Geological Fieldwork and Current Research*, the premier annual publication of the Geological Survey Branch.

In 1986 the Branch mounted the largest field program in our 91-year history, largely as a result of increased funding under the Canada/British Columbia Mineral Development Agreement. The Branch increased its commitment to the priority areas of mineral deposit studies, geochemistry and database development. A new program of 1:50 000-scale regional mapping was initiated in 1986 in the Cowichan, Taseko Lakes, Whitesail Lake and Midway areas. Papers detailing results of the first season's work on these projects are included in this volume.

In the past year all of the metallic mineral deposit field studies undertaken by Branch geologists were oriented towards precious metals. Old camps such as Hedley and Bralorne were re-evaluated and emerging districts such as Quesnel were mapped at regional 1:50 000 scale for the first time. A number of industrial mineral investigations were also undertaken, reflecting growing industry interest in this field. These studies included evaluation of the potential for production of such diverse commodities as zeolites, phosphate, olivine and dimension stone.

The Geological Survey Branch funded a number of studies and theses at the Department of Geological Sciences at The University of British Columbia which are also reported in this volume. The topics covered include wallrock alteration at the Erickson gold mine, an analysis of the effects of seasonal variations in stream flow on the gold content of stream sediments, palynology in the Northeast Coalfield, lead isotope research and a number of specific mineral deposit studies.

The second year of a mineral resource evaluation of the Chilko Planning Area was completed by staff of the Land Use subsection. Detailed silt geochemistry in this area has aided in the identification of a number of new mineral occurrences.

To further the reputation of this volume as a major reference on current research in the earth sciences, we have added a section listing recently completed theses on the geology of British Columbia and related topics.

The volume was edited and compiled by John Newell and Rosalyn Moir; the effort required to achieve timely publication is gratefully acknowledged.

W. R. SMYTH
Chief Geologist
Geological Survey Branch
Mineral Resources Division

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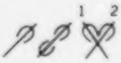
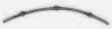
SYMBOLS USED ON GEOLOGICAL MAPS AND FIGURES

Drift-covered area (LEFT BLANK)

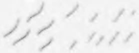
Glacial striae (direction of ice movement known, unknown) (Numbers indicate relative age, 1 being the oldest.)



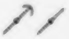
End moraine



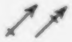
Minor moraines, rib moraines, washboard moraines, 'annual' moraines, till ridges transverse to ice flow (irregular, straight)



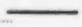
Drumlins, drumlinoid ridges (direction of ice movement known, unknown)



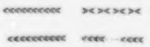
Crag and tail hills and ramps



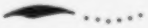
Glacial linear feature



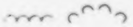
Esker (direction of flow known, unknown)



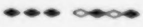
Esker (continuous, discontinuous)



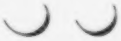
Raised beaches



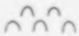
Limit of marine or lacustrine submergence (well marked, assumed)



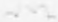
Dunes



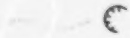
Area of sand dunes



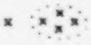
Landslide scar



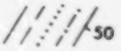
Escarpment, cirque



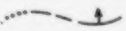
Rock outcrop, area of outcrop, probable outcrop



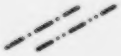
Geological boundary (defined, approximate, assumed, gradational, dip indicated)



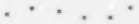
Intrusive contact with younger unit indicated



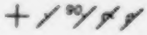
Unconformity (defined, assumed)



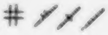
Limit of geological mapping



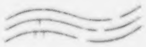
Bedding, tops known (horizontal, inclined, vertical, overturned)



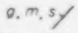
Bedding, top unknown (horizontal, inclined, vertical, dip unknown)



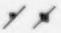
Bedding, general trend (dip unknown, top unknown; dip and top known; dip known, top unknown)



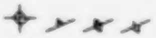
Bedding, estimated dip (gentle, moderate, steep)



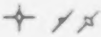
Igneous flow banding (inclined, vertical)



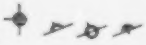
Primary igneous layering, tops known (horizontal, inclined, vertical, overturned)



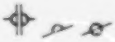
Primary igneous layering, tops unknown (horizontal, inclined, vertical)



Strike and dip of pillows, tops known (horizontal, inclined, vertical, overturned)

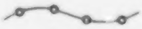


Strike and dip of pillows, tops unknown (horizontal, inclined, vertical)



Volcano

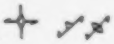
Flow contact



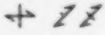
Roof pendant (unit number indicated; too small to map separately)

Schistosity, cleavage, foliation; used where ages of foliation are indicated on the map (horizontal, inclined, vertical):

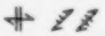
Schistosity of unknown age



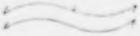
S_1

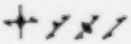


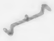
S_2

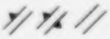


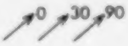
SYMBOLS USED ON GEOLOGICAL MAPS AND FIGURES—*Continued*

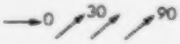
Schistosity, gneissosity, cleavage, foliation, general trend 

Gneissosity, foliation or banding (horizontal, inclined, vertical, dip unknown) 

Shearing and dip 

Axial plane of minor fold (inclined, vertical, dip unknown) 

Axes of minor folds (horizontal, inclined, vertical) 

Lineation of unknown age (horizontal, inclined, inclined but plunge unknown, vertical) 

Type of lineation denoted by letter:

Mineral lineation

S intersections

Microcrenulations

Boudin axes

Deformed clasts

Igneous inclusions

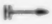
Rodding, mullion structure

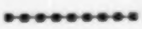
Metamorphic aggregates

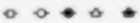
Deformed pillows

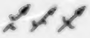
Age of lineation and of minor fold axes:

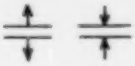
L_1

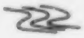
L_2 

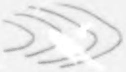
Mineral isograd 

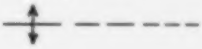
Other alternatives when more than one mineral isograd 

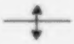
Sense of vergence of minor structures (used with minor fold axis symbol or lineation S intersection symbol; read looking along the arrow) 

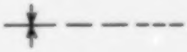
Box anticline, box syncline 

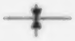
Fold 

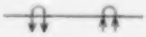
Structural trend (from aerial photographs) 

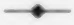
Anticline (defined, approximate, assumed) 

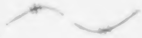
Antiform 

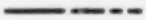
Syncline (defined, approximate, assumed) 

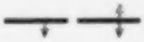
Synform 

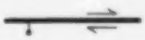
Anticline and syncline (overturned) 

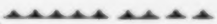
Antiform or synform 

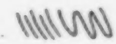
Lineament (from aerial photographs) 

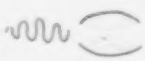
Fault (defined, approximate, assumed) 

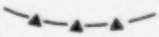
Fault (inclined, vertical) 

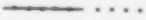
Fault (solid circle indicates downthrown side, arrows indicate relative movement) 

Thrust fault (teeth in direction of dip; defined, approximate, assumed) (teeth indicate upthrust side) 

Zone of numerous imbricate thrust faults 

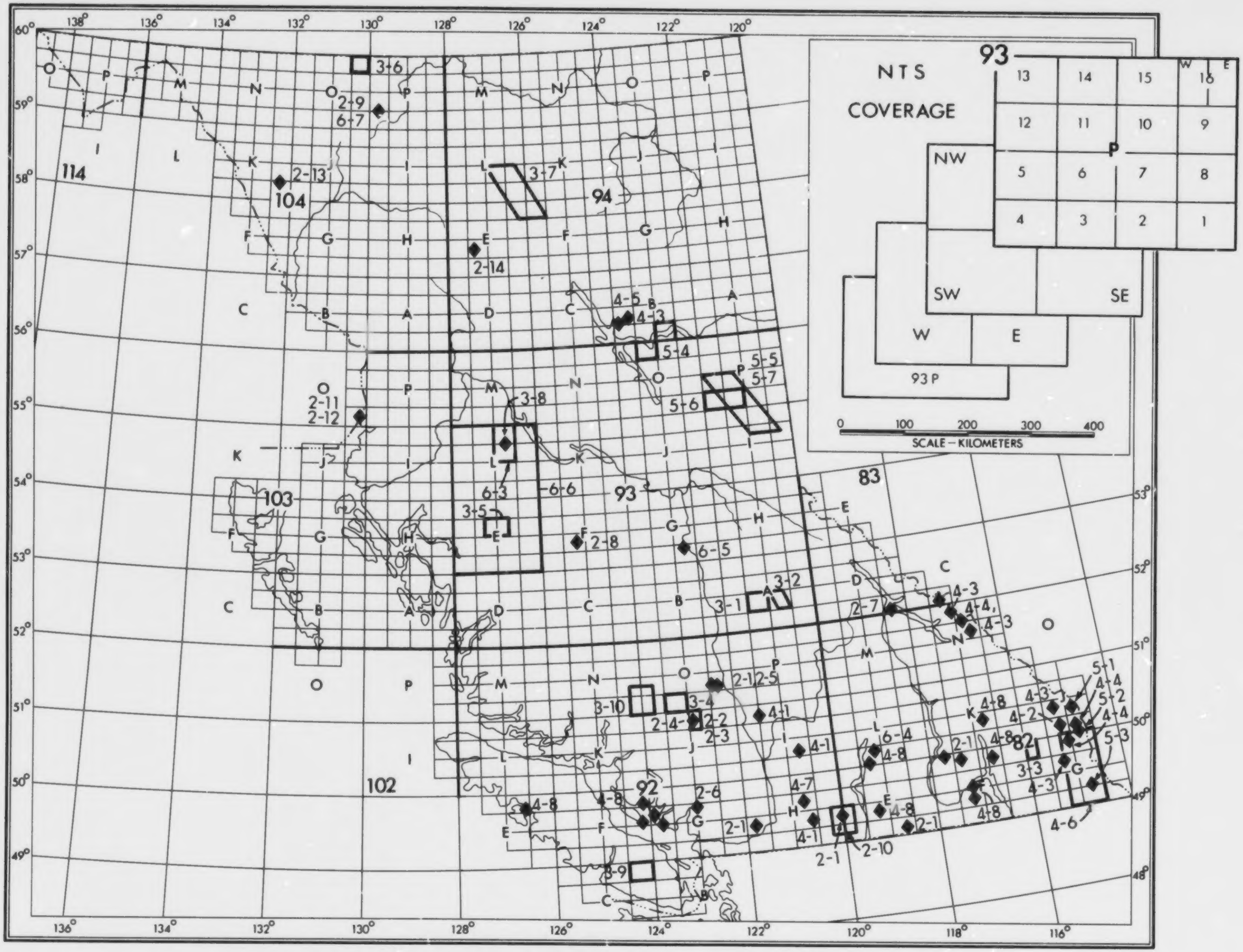
Fault zone, shear zone (width indicated) 

Tectonic slide 

Vein fault (defined, assumed) 

SYMBOLS USED ON GEOLOGICAL MAPS AND FIGURES—*Continued*

Mineralized bed or seam (hematite)	hem —•—•— hem • • • •
Dyke, vein or stockwork (defined, approximate, assumed; dip indicated)	IIIIIII III III II ╨ 30
Joint (horizontal, inclined, vertical)	✛ ⁄ ⁄
Sheeted dykes (horizontal, inclined, vertical)	┼ ┼ ┼
Fossil locality	Ⓕ
Locality where age has been determined, in millions of years	Ⓐ 1400
Location of measured section	⌒
Gravel pit or quarry (active, abandoned)	× ×
Borrow pit (active, abandoned)	⧖ ⧖
Open-pit mine or quarry	⬭
Rock dump or tailings	'''''''''
Rock quarry (active, abandoned)	⚒ ⚒
Mine (lead, zinc)	⚒ Pb Zn
Mine (lead, zinc; abandoned)	⚒ Pb Zn
Mineral prospect; mineral occurrence (manganese)	× 3 × Mn
Placer deposit (gold)	× Au
Show of oil and gas (abandoned)	✸
Show of gas (abandoned)	☼
Gas producer	○
Oil producer	☼
Oil and gas producer	●
Dry (abandoned)	✧
Location of drilling	○
Trace of coal seam	▬ ▬ ▬ ▬
Shaft, raise, winze	◧ ◧ ◧
Shaft (abandoned)	◧
Trench	⌶
Opencut	⩍
Adit or tunnel portal	≻— ≻═
Adit or tunnel (caved)	≻⁄ ≻≠
Borehole	● BH ● BH2
Diamond-drill hole	● DDH
Sinkhole	○ SH
Gossan, limonite capping	G G ▨ G


NTS
COVERAGE
93
13
14
15
16
W
E
12
11
10
9
P
5
6
7
8
4
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2
1
NW
SW
SE
W
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93 P
0
100
200
300
400
SCALE — KILOMETERS
114
104
94
103
93
83
102
92
82
60°
59°
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4-3
4-4,
4-3
2-12-5
3-10
3-4
2-4
2-2
2-3
4-1
4-1
6-4
4-8
4-8
2-1
4-8
4-3
4-2
5-1
4-4
5-2
4-4
5-3
3-3
4-3
4-6
4-8
2-6
2-1
4-7
4-1
2-1
2-10
4-8
2-1
4-8
4-8
4-8
3-9

Figure 1-1-1. Location map for programs reported in Geological Fieldwork 1986.

Mineral Deposit Studies

BRIEF STUDIES OF SELECTED GOLD DEPOSITS IN SOUTHERN BRITISH COLUMBIA*

By T. G. Schroeter

INTRODUCTION

As a follow up to studies on gold deposits in northern British Columbia over the last several years, the writer made brief visits to the following gold deposits or areas in southern British Columbia: Abo, Blackdome, Bralorne-Bridge River, Grand Forks-Greenwood, Hedley, Tillicum and Willa. The overall goal is to study the great variety of significant gold-bearing mineral deposits in British Columbia and produce a written summary of "type" deposits, including such topics as: regional and local geology, composition of host rocks, age of host rocks, structural controls, mineralogy of 'ore' and gangue, alteration assemblages, fluid inclusion and isotope data (if available), age of alteration and/or mineralization, classification of deposit and deposit correlations/comparisons including modelling and metallogenesis.

Writing is expected to begin after one more field season with a target completion date in spring 1988.

Some descriptions are longer than others, depending on the availability of expanded write-ups by other authors in past volumes of Geological Fieldwork or this volume.

ABO (ex-RN) — MI 092H/SW-092 (Lat. 49°20′N; Long. 121°45′W; 92H/5)

The Abo gold prospect is located at the southeastern corner of Harrison Lake, 4.5 kilometres northeast of the village of Harrison Hot Springs (Plate 2-1-1). Kerr Addison Mines Ltd., under an option agreement with Abo Oil Corp., is currently exploring for large tonnage, low-grade gold deposits amenable to low cost underground mining.

HISTORY

The Abo property was also known as the RN (pre-November 1984) and the GEO (pre-August 1975). Between 1973 and 1981,

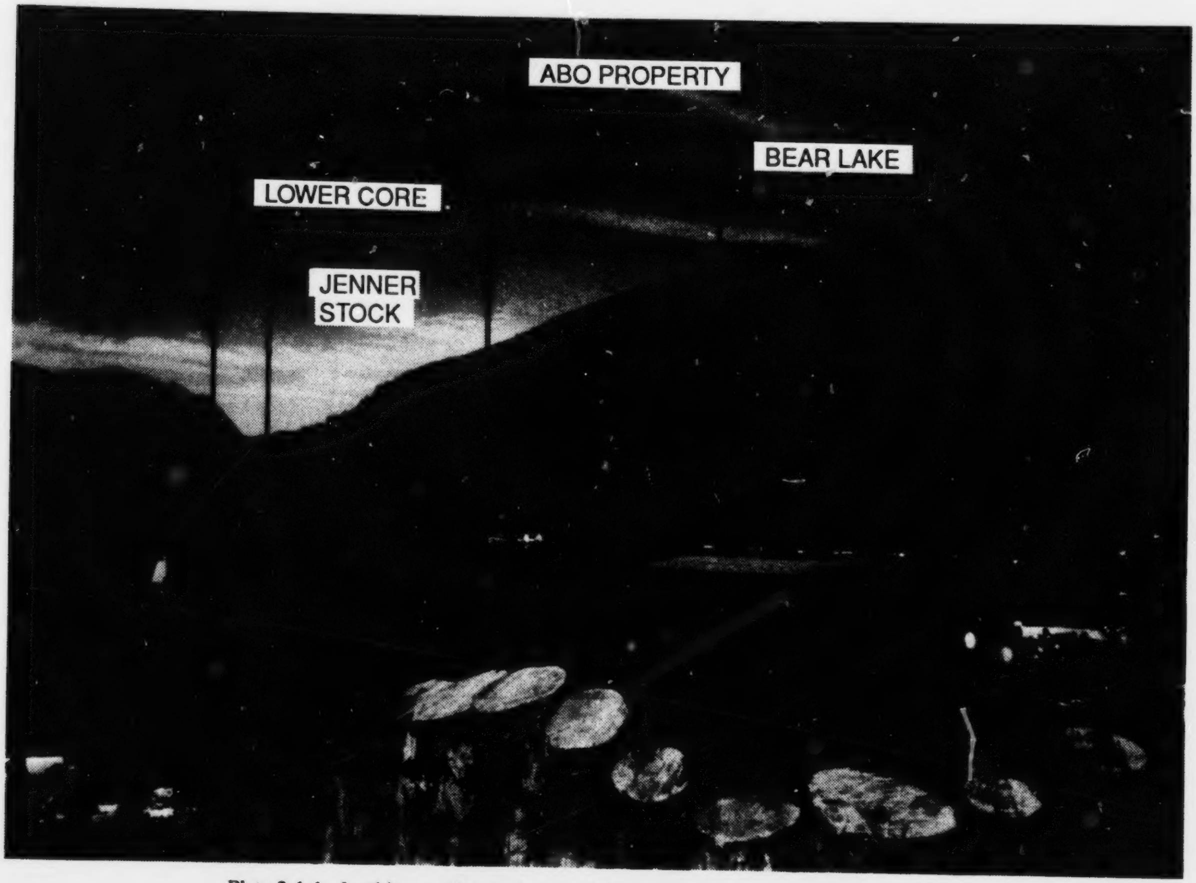

Plate 2-1-1. Looking northeasterly toward Abo property from Harrison Hot Springs.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

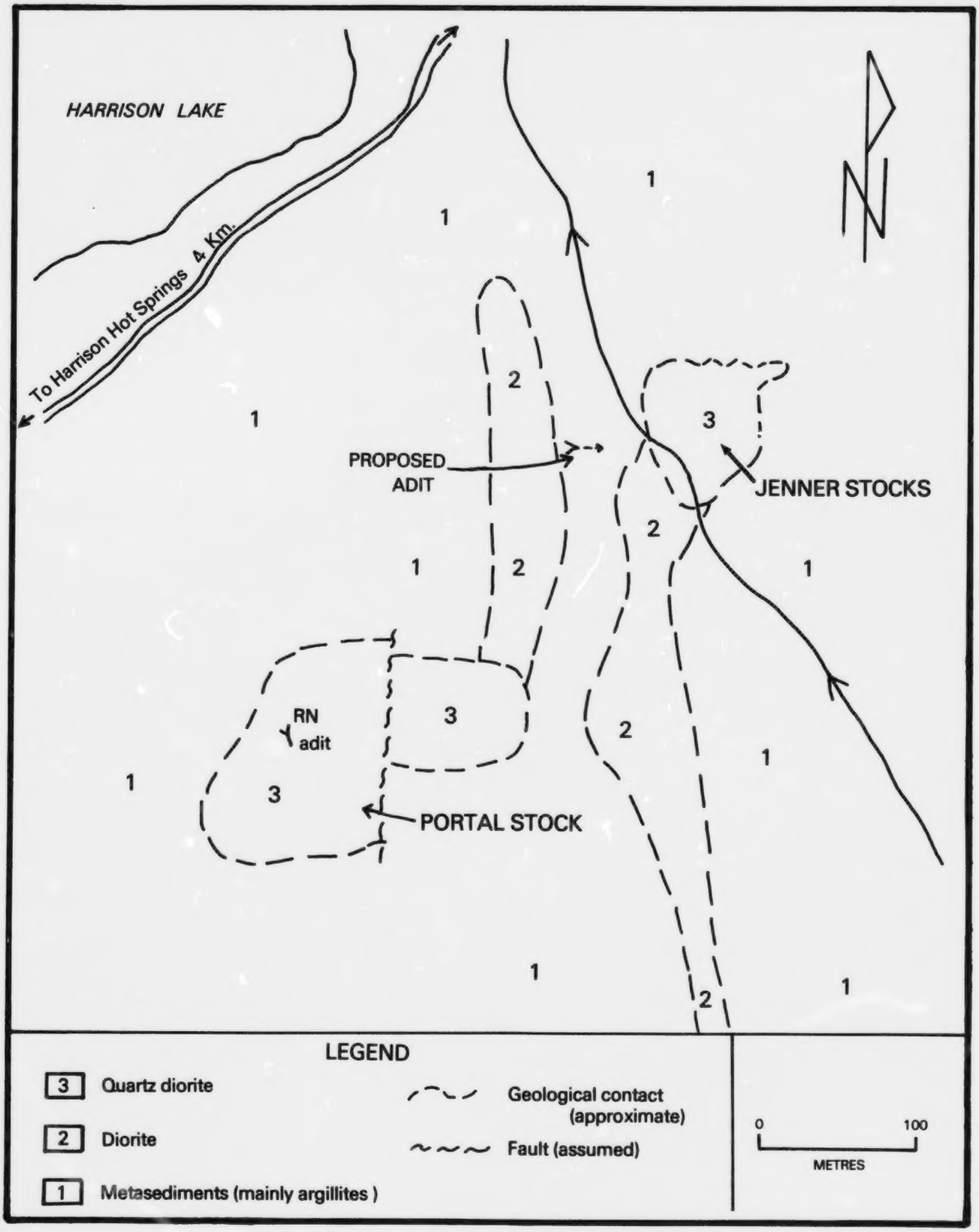
HARRISON LAKE
To Harrison Hot Springs 4 Km.
1
1
1
1
2
2
2
2
2
3
3
3
PROPOSED ADIT
JENNER STOCKS
RN adit
PORTAL STOCK
N
LEGEND
3 Quartz diorite
2 Diorite
1 Metasediments (mainly argillites)
Geological contact (approximate)
Fault (assumed)
0
100
METRES

Figure 2-1-1. Geology of Abo gold prospect (after company plans).

642.8 tonnes of ore was mined in a 50-metre-long adit from a pyrrhotite-rich quartz vein 10 to 40 centimetres thick. A total of 30 443 grams of gold and 616 kilograms of copper was recovered. Between 1982 and 1986 geological, geochemical and geophysical surveys and 6075 metres of diamond drilling were carried out on the property. The average grade of eight drill intersections of the vein was 4.8 grams of gold per tonne.

To September 1986, Kerr Addison drilled 1971 metres in fifteen NDB-size diamond-drill holes, twelve in the Jenner stock and three in the Portal stock (Plate 2-1-1).

GEOLOGY

Host rocks in the vicinity of mineralized zones are primarily argillites of the Upper Jurassic Mysterious Creek Formation. They have been intruded and moderately hornfelsed by stocks (apophyses) of quartz diorite related to the mid-Tertiary (Miocene) Hicks Lake stock to the east. Plutons range from 50 to 200 metres in diameter. The Mysterious Creek Formation is separated from the Chilliwack Group to the northeast and southwest by the north-northwest-trending Harrison Lake strike fault. At least four quartz diorite stocks have been identified on the property; the Portal and Jenner stocks have been drilled (Figure 2-1-1).

STRUCTURE

A belt of mineralized and unmineralized quartz dioritic stocks lies within the Harrison Lake fracture system which has been traced for several hundreds of kilometres in a northwesterly direction and is assumed to cross the Abo property.

MINERALIZATION

Gold occurs in a "network" of quartz veinlets, quartz veins and quartz-filled microfractures, believed to have developed through a process of microfaulting and fracturing of subvertical plug-shaped quartz diorite stocks followed by injection of gold-bearing solutions along fractures. Contacts between veins and wallrocks are generally sharp. Quartz veins pinch and swell, ranging in thickness from 1 millimetre to 40 centimetres. They most commonly occupy tension fractures and die out rapidly in argillites.

Total sulphide content averages 5 per cent and includes pyrrhotite and pyrite with minor chalcopyrite, sphalerite, arsenopyrite and trace molybdenite. The gangue minerals are predominantly quartz with minor sericite and adularia. The sericite in the veins gives a potassium-argon age of 24.5 ± 1 million years (Ray *et al.*, 1985) which is accepted as the age of gold mineralization. This date coincides closely with other potassium-argon ages of dioritic plutons along the Harrison Lake fault system.

Native gold and rucklidgeite (a lead-bismuth telluride) appear to have a spatial and possibly a genetic association in quartz veins, both on the Abo property and elsewhere along the fault system. The following microprobe analysis on a telluride specimen submitted by the writer was provided by Dr. Don Harrison at the Geological Survey of Canada: 43.9 per cent bismuth, 9.6 per cent lead, 45.2 per cent tellurium, total 98.7 weight per cent, corresponding to $Pb_{0.52}Bi_{2.38}Te_{4.00}$. This is the third recorded occurrence in Canada, the first being from the Robb Montbray gold deposit in Quebec and the second from the Ashley gold deposit in Ontario.

GEOCHEMISTRY

Gold geochemistry in rocks and soils is effective. There appears to be no enhancement of other elements, including silver.

ORE GENESIS

A synchronous dioritic plutonic and gold mineralizing event is postulated to have occurred along the Harrison Lake fracture system during the period of 19 to 26 million years before present.

ACKNOWLEDGMENTS

I would like to thank Ray Dujardin, Thor Bruland and Art Clendenan of Kerr Addison Mines Ltd. for their hospitality on the property and office discussions concerning the Abo project. Dr. Don Harris very kindly provided microprobe and X-ray analysis data on a telluride sample submitted from the property.

BLACKDOME DEPOSIT — MI 92O-050, 051, 052, 053 (Lat. 51°19'N; Long. 122°30'W; 92O/7E, 8W)

The Blackdome gold mine commenced production in May 1986 at a rate of approximately 150 tonnes per day; doré bars contain approximately 65 per cent gold and 35 per cent silver. Initial reserves were 184 120 tonnes grading 27.09 grams of gold and 128.9 grams of silver per tonne, based on a cut-off grade of 8.57 grams of gold per tonne and allowing for 21 per cent mining dilution. The total cost of the project is estimated to be $18 million ($10 million for mill construction, $7.5 million on exploration and $0.5 million on development). Depending on several factors, including the price of gold, the payback period at the mine may be less than two years.

EXPLORATION — DEVELOPMENT

A program of surface and underground exploration in the South mine, completed in May and June 1986, identified an additional 21 770 tonnes of ore grading approximately 60 grams of gold per tonne in the No. 3 oreshoot on the No. 2 vein, increasing gold reserves by nearly 1300 kilograms. The No. 3 shoot was traced by drilling over a strike length of 38 metres and has an average width of 2.27 metres. Drilling along the vein system has tested mineralization to a depth of 125 metres. Surface drilling along the southerly extension of the vein system, across the northwesterly trending fault shown on Figure 13-1 (Faulkner, 1986) has intersected additional ore-grade mineralization.

GEOLOGY

The Blackdome deposit is a high-level explosive epithermal quartz vein and/or quartz breccia system which intruded volcanic rocks of Eocene age. The volcanic sequence consists of a lower andesitic unit (not seen in the mine section) overlain by a flow-banded rhyolite (including ignimbrites with trachytic and pilotaxitic textures) and ash flow tuffs, in turn overlain by an upper andesite with local deposition of a volcanic wacke at its base. Mineralization is primarily hosted by the rhyolite unit but also occurs in the upper andesite. A younger postmineral basalt (24 ± .08 million years) overlies the entire sequence and caps Blackdome Mountain (Plate 2-1-1).

ECONOMIC GEOLOGY

To date 12 quartz veins have been identified all dipping steeply to the northwest (*see* Faulkner, 1986, page 106). The No. 1 and No. 2 veins coalesce toward the southern end of the vein system. Veins have been traced over a strike length in excess of 2500 metres with widths averaging 1.5 to 2 metres (Plate 2-1-2). Cockscomb textures, vugs, and brecciation are common features in "ore". Gangue is chiefly silica with a noticeable lack of carbonate. Total sulphide content is low (less than 0.5 per cent), with native gold the major ore mineral.

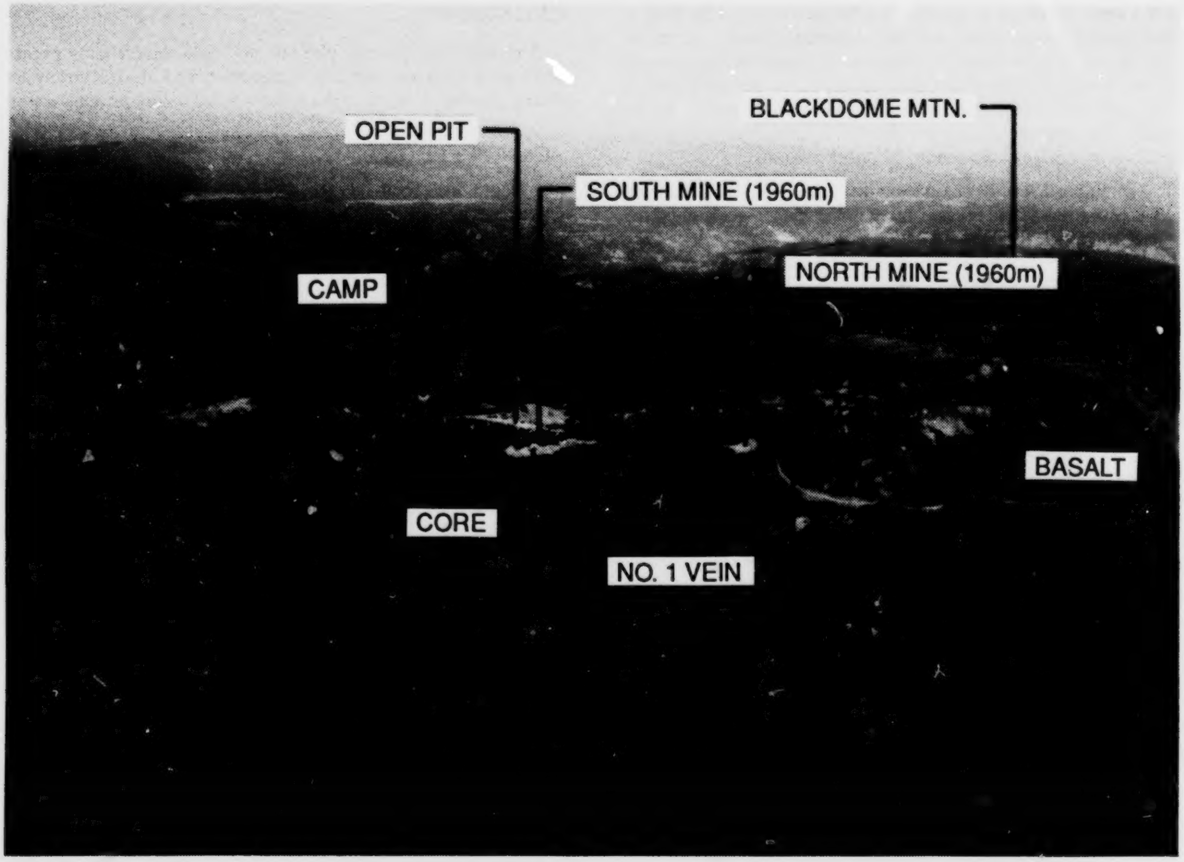

Plate 2-1-2. Looking westerly over Blackdome mine.

GEOCHEMISTRY

A strong correlation between gold, arsenic and antimony exists in wallrock samples.

Gary Vivian at the University of Alberta has identified two selenium-bearing minerals in the ore: aguilarite (Ag_2Se) and naumannite [$Ag_2(Se,S)$]. Although no barite has been noted to date, Vivian has also identified a barium-rich feldspar (celsian) which may represent a replacement phenomenon. Preliminary oxygen isotope data indicate a very consistent geothermal system dominated by meteoric water ($\sigma^{18}O\%$ fluid ranges from -7.5 to -8.96) (G. Vivian, private company files, 1985).

ALTERATION

Besides the obvious silicification in rocks adjacent to ore, other alteration minerals identified include: sericite, kaolinite, montmorillonite, illite, chlorite, epidote and adularia.

ORE GENESIS

The Blackdome deposit is postulated to have formed at the top of a large hydrothermal intrusive system similar to the Poison Mountain porphyry copper deposit (estimated reserves at 175 million tonnes averaging 0.33 per cent copper, 0.015 per cent molybdenum and 0.3 grams of gold per tonne) located approximately 20 kilometres to the south. The intrusive source is postulated to have been anomalous in gold and silver. Metals were deposited as a result of the explosive upward movement of hydrothermal solutions into permeable rhyolitic and, to a lesser extent, andesitic rocks. The Blackdome deposit is considered to be a good example of the "classic" Tertiary bonanza epithermal deposits found in the southwest U.S.A.

PRODUCTION

An increase in the milling rate from 150 to 200 tonnes per day is planned, with feed coming from at least six stopes and surface mining on the No. 1 vein. A glory hole will eventually be developed by stoping to the surface. Milling recovery is estimated at 90 per cent. Some 50 to 60 per cent of the gold is recovered in jig concentrates prior to flotation. Concentrates containing about 30 per cent gold are upgraded by repeated processing across a shaker table.

Production is expected to be approximately 140 kilograms of gold and 700 kilograms of silver per year. The potential for discovery of additional reserves is considered excellent.

ACKNOWLEDGMENTS

The writer thanks Dave Rennie (Mine Geologist) and Bob Roscoe (Mine Manager) for their generous hospitality and valuable discussions on property geology and mining.

BRALORNE-BRIDGE RIVER GOLD CAMP
(Lat. 50°38′N to 50°59′N; Long. 122°32′ to 122°57′W; 92J/15)

The Bralorne-Bridge River district ranks as the premier gold camp in British Columbia having produced 143 240 kilograms of gold from some eight million tonnes of ore during the period 1932 to 1971 (Schroeter and Panteleyev, 1986). Evidence of an igneous and hydrothermal "system" has been traced for over 6 kilometres (Leitch and Godwin, 1986). A spatial relationship exists between quartz veins, mineralization and sodic intrusions. Veins range from a few metres to thousands of metres in horizontal and vertical extent with widths averaging between 0.75 to 1.5 metres. They are generally sulphide poor (1 to 3 per cent) and contain native gold with minor pyrite, arsenopyrite and trace sphalerite, galena, chalcopyrite and tetrahedrite. Ribbon textures are common; locally mariposite occurs along vein margins.

Present reserves of "readily available" ore at the Bralorne mine are estimated at 475 000 tonnes grading 8.91 grams of gold per tonne. Total reserves are estimated at 830 174 tonnes grading 8.57 grams of gold per tonne (E&B Explorations Inc., Stage I Report, 1982). Drilling from surface and underground on the 800 level indicates continuity in the Ida May, Alhambra, Alhambra F.W., 809, 51 F.W. and 51 veins.

The historic Bralorne-Pioneer deposits (MI 92J/NE-001 to 004, 006 to 008) are examples of mesothermal or Motherlode-type precious metal deposits.

The Congress deposit (MI 092J/NE-029) contrasts with the Bralorne deposits in that the veins are generally enriched in sulphides and contain significant amounts of stibnite. They may have formed at higher elevations in the hydrothermal system. Reserves at Congress in the Howard, Lou, Congress and Paul zones, are estimated at 607 400 tonnes grading 8.23 grams of gold per tonne in all categories.

References which describe recent work in this camp in more detail include Leitch and Godwin (1986), Harrop and Sinclair (1986), Church (this volume) and Leitch (this volume).

HEDLEY — MI 092H/SE-038, 039
(Lat. 49°22′N; Long. 120°02′W; 92H/8, 82E/5)

A brief surface and underground visit was made to this important district where gold-bearing sulphide-rich skarn deposits are spatially associated with diorite intrusions.

Mascot Gold Mines Limited is preparing the Nickel Plate mine for production at a rate of 2450 tonnes per day. Using a cutoff of 1.714 grams of gold per tonne, open-pit reserves are estimated at 6 429 700 tonnes grading 5.142 grams of gold per tonne with a 9.1:1 stripping ratio. An additional 2 358 200 tonnes of reserves grading 5.49 grams of gold per tonne have been outlined below the design pit bottom.

More detailed descriptions of the Hedley area are included in Ray *et al.* (1986) and Ray and Dawson (this volume).

The management and staff of Mascot Gold Mines are gratefully acknowledged for taking time out of their busy schedule to provide a tour of the property. Gerry Ray very kindly provided a regional overview of the Hedley district.

GRAND FORKS-GREENWOOD
(Lat. 49°05′N; Long. 118°35′W; 82E)

Several gold occurrences in the historic Grand Forks-Greenwood skarn camp were visited:

(1) **Phoenix** (MI 082E/SE-020) where skarn mineralization has been extensively mined in the past, both underground and by open pit. Over the period 1900 to 1978 the Phoenix mine produced 28 083 kilograms of gold, 183 036 kilograms of silver and 235 693 tonnes of copper from a little over 13 million tonnes of ore milled.

(2) **Jewel (Dentonia)** (MI 082E/SE-055) where 117 910 tonnes of ore averaging 10.3 grams of gold and 68.6 grams of silver per tonne were produced from the Jewel and Enterprise orebodies during the period 1895 to 1975. The vein system, containing galena, native gold, chalcopyrite and pyrite in a quartz, calcite and barite gangue, is hosted by granodiorite and has been traced over a strike length of 975 metres.

(3) **Sylvester K** (MI 082E/SE-046) where a gold-bearing massive sulphide lens has been outlined in a hornfelsed dust tuff and argillite unit. The lens is 305 metres long, averages 9.1 metres in width and has been drilled to a depth of 37 metres. Assays up to 10.3 grams per tonne gold have been obtained over a width of 2.4 metres of massive pyrite-pyrrhotite-chalcopyrite-magnetite mineralization within the broader zone.

(4) **Rainbow (ex Midway mine)** (MI 082E/SE-128) where altered ultramafic rocks are in faulted contact with high-silica "cap" rocks, a potentially favourable geologic environment for gold deposition.

(5) **OB** (MI 082E/SE-011) where Skylark Resources Ltd. and Viscount Resources Ltd. have recently completed a 178-metre decline on a narrow silver-rich vein in quartz diorite.

The two significant types of gold-silver deposit in the Grand Forks-Greenwood area are: (1) skarns related to buried intrusive bodies; and (2) epithermal veins controlled by low-angle Tertiary faults (detachment zones?) recently recognized by Dr. J.T. Fyles.

The hospitality and information provided by George Stewart and Jim Fyles, both with Kettle River Resources Ltd., is gratefully acknowledged.

TILLICUM — MI 082F/NW-234
(Lat. 49°59′N; Long 117°43′W; 82F/13, 82K/4)

PREVIOUS WORK

The geology and geochemistry of the Tillicum Mountain area are discussed in previous reports (Ray and Spence, 1986 and Ray *et al.*, 1986).

During 1985, 58 902 grams of gold were produced from 2902 tonnes of ore processed at the Dankoe mine custom mill near Keremeos. Ore was mined from the Heino-Money pit, which is now 153 metres long, 61 metres deep and averages 2.5 metres in width.

1986 WORK

Surface diamond drilling and underground drifting on the 2130 level (Money drift) resulted in the discovery of a new east-trending high-grade gold shoot crosscutting the Heino-Money zone and extending the Screamer shoot to depth within it. The Screamer shoot, the richest ore shoot discovered to date, is now at least 31 metres deep; raising within it will define new underground reserves and add to the stockpile of high-grade ore. In fall 1986 approximately 1090 tonnes of stockpiled ore, with an average grade of 58.3 grams per tonne gold, was custom milled at the Roberts mine near Greenwood.

MINERALIZATION

Native gold is associated with a chlorite-sericite calc-silicate skarn developed near the contact between metabasalt and meta-argillite. The skarn is pinkish green to light brown in colour, often banded, and sometimes cut by quartz veinlets.

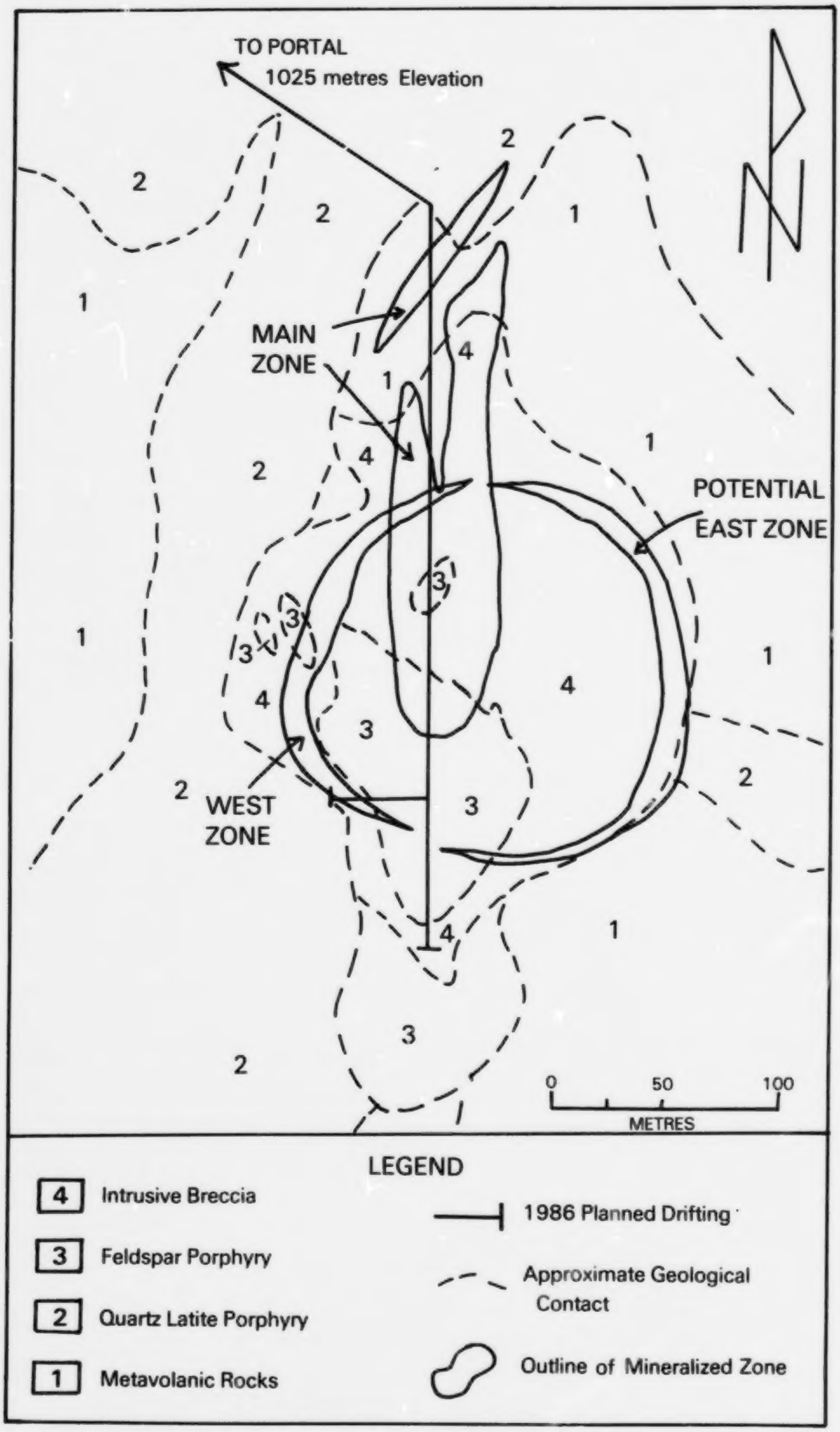
TO PORTAL
1025 metres Elevation
MAIN ZONE
POTENTIAL EAST ZONE
WEST ZONE
1
2
3
4
0
50
100
METRES
LEGEND
4 Intrusive Breccia
3 Feldspar Porphyry
2 Quartz Latite Porphyry
1 Metavolanic Rocks
1986 Planned Drifting
Approximate Geological Contact
Outline of Mineralized Zone

Figure 2-1-2. Geology and planned drifting, Willa prospect (after company plans).

ACKNOWLEDGMENTS

The writer gratefully acknowledges the hospitality and field discussions with Bernie Dewonk, project geologist with Esperanza Exploration Ltd.

WILLA (AYLWIN CREEK) DEPOSIT — MI 082F/NW-070, 071

(Lat. 49°53′N; Long 117°22′; 82F/14)

The Willa gold-copper-silver breccia lies 12 kilometres south of New Denver (Plate 2-1-3). Northair Mines Ltd. holds the property under an option agreement with BP Minerals Ltd. and Rio Algom Exploration Inc. At the end of July 1986, Northair had completed approximately 22 000 metres of surface and underground diamond drilling and 1000 metres of drifting at an estimated cost in excess of $7 million. Five hundred tonnes of ore from underground have been stockpiled.

GEOLOGY

A steeply dipping, arcuate, heterolithic breccia pipe, with an arc length of 200 metres, an average thickness of 20 metres and a minimum vertical extent of 150 metres, is intrusive into a quartz latite porphyry. The porphyry is host to quartz molybdenite stockwork mineralization and both the pipe and porphyry are contained within a pendant of hornfelsed mafic volcanic rocks of probable Lower Jurassic Rossland Formation (Figure 2-1-2).

MINERALIZATION

Chalcopyrite, pyrite, pyrrhotite and microscopic native gold occur within the intrusive breccia pipe and at its margins. Three zones of gold-bearing mineralization have been identified; in-filling crackle breccia textures are particularly well developed in the West Zone.

As of July 1986 reserves were quoted by the operator at:

(1) **Near-Surface Main Zone**: Approximately 3.4 million tonnes grading 1.34 grams of gold per tonne gold, 0.32 per cent copper and 4.8 grams of silver per tonne.

(2) **West Zone**: Approximately 1.8 million tonnes grading 2.93 grams of gold per tonne, 0.66 per cent copper and 9.3 grams of silver per tonne, including a higher grade section of approximately 849 400 tonnes grading 5.49 grams of gold per tonne and 0.82 per cent copper.

(3) **East Zone**: An east zone has been intersected by underground drilling but reserves are not available.

There appears to be a positive correlation between better gold grades and the presence of anhydrite ± garnet.

Re-evaluation of data and new reserve calculations are currently in progress.

AGE DATING

Samples collected for zircon age dating by Dr. W.J. McMillan of the B.C. Ministry of Energy, Mines and Petroleum Resources are currently being processed.

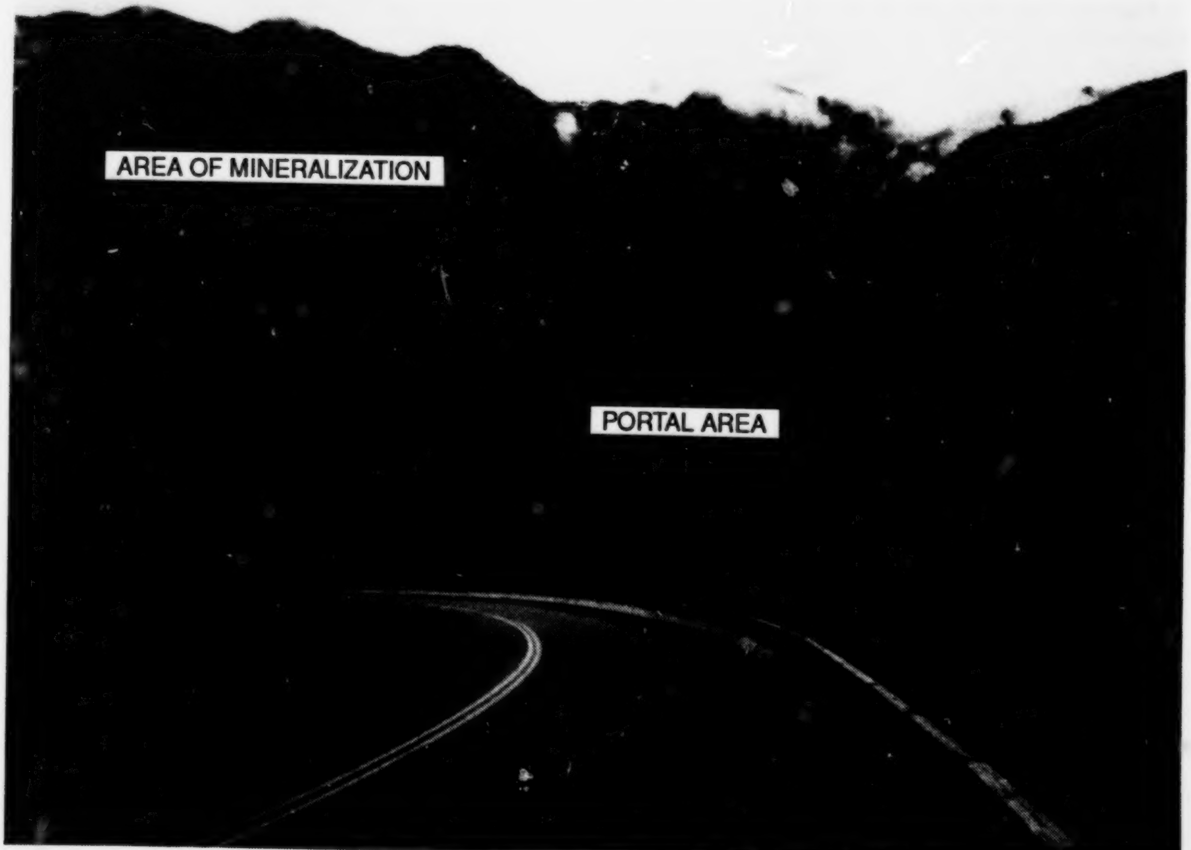

Plate 2-1-3. Looking southeasterly from Highway 6 toward Willa property.

DEPOSIT TYPE

The Willa deposit is thought to represent a hydrothermal, intrusive breccia system of alkaline affinity and containing significant quantities of gold, copper and silver. The nature of the volcanic country rocks, the occurrence of ring and radial dyke complexes and the presence of intrusive breccia suggest a preserved volcanic centre. As suggested by Heather (1985) the Willa system may be the root zone of a gold vein system similar to that at Rossland, one of British Columbia's major gold-producing mining districts.

ACKNOWLEDGMENTS

I am grateful to Len Werner (contract geologist with Northair) for guiding my underground tour and to Fred Hewitt (Northair) and Russ Wong (BP) for office discussions on the Willa project.

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GEOLOGY AND MINERALIZATION OF THE BRIDGE RIVER MINING CAMP

(92J/15, 92O/2, 92J/10)

By B. N. Church

INTRODUCTION

The Bridge River mining camp, centred 185 kilometres north of Vancouver, covers an elliptical area of mountainous terrain bounded roughly by Tyaughton Creek on the north and Cadwallader Creek on the south (Figure 2-2-1). The camp has 73 mineral localities including the Bralorne-Pioneer mining complex which attained the status of the foremost gold producer in British Columbia and sixth largest in Canada.

Regional mapping and property evaluations in the camp, covering parts of the Bralorne, Noaxe and Birkenhead NTS sheets, were initiated by the Ministry in response to intense mineral exploration activity stimulated by rising gold prices.

The area is underlain by 15 mappable units comprising bedded volcanic and sedimentary assemblages and a variety of intrusive igneous rocks ranging from Paleozoic to Tertiary age. These units are faulted and locally invaded by quartz veins which form the loci of gold mineralization (Figure 2-2-2).

ACKNOWLEDGMENTS

Mapping and property examinations were carried out with the able assistance of Mary MacLean.

Much appreciation is owing the mining and mining exploration personnel of the Gold Bridge-Bralorne area, especially Drs. B. Cooke of Levon Resources Ltd. and J. Dawson of Kerr, Dawson & Associates Ltd. and to C. Leitch of The University of British Columbia, for informative discussions.

Officers of the Geological Survey of Canada, Drs. K. Dawson, G. Woodsworth and Margaret Rusmore, provided valuable scientific support in this investigation.

BEDDED ROCKS

The principal stratigraphic assemblages of the area are the Fergusson, Cadwallader and Taylor Creek Groups. The name Big Sheep Mountain volcanics is applied informally to a small area of Tertiary lavas and pyroclastic rocks in the northeast part of the camp (Figure 2-2-3).

The Fergusson Group is the oldest known unit in the area (pre-Permian age?). Where best developed on Mount Fergusson, the group consists of steeply dipping chert beds, some marble, schist, gneiss and hornfels (Figure 2-2-4). Chert is the most common rock type, attaining a thickness of 1000 metres or more. The beds are typically thin ribbons of recrystallized light and dark grey quartz, with a few jasper zones and more rarely, green quartz.

Locally the beds are intricately folded and crisscrossed by thin quartz veinlets. In some places cataclasis has reduced bedding laminations to sheared quartz lenses and intensely milled breccias resembling quartz pebble conglomerate.

Impurities in the chert are mostly white mica interlayers and graphitic schist. In the contact aureoles of the major granitoid intrusions the formation is transformed into highly deformed garnet-biotite-quartz gneiss.

The base of the Fergusson Group is nowhere visible. The only marker horizon is a thin marble band, 1 to 10 metres thick, observed infrequently across the map area.

Locally the group is invaded by numerous greenstone dykes and sills. In zones of intense shearing these feeders are reduced to chlorite schist; in the thermal aureoles of the large granitic stocks fine-grained amphibolite is formed from these basic intrusions.

The Cadwallader Group is Upper Triassic age and composed of three formations, namely the Pioneer Formation, Noel Formation and Hurley Formation. The group is best exposed in the northwest and southeast parts of the map area.

The Pioneer Formation is apparently the oldest unit in the Cadwallader Group and consists of greenstones — chlorite and epidote-bearing basic volcanics. These rocks appear to be connected to the greenstone feeders which intrude the underlying Fergusson Group. The common manifestations of the unit are pillow lavas, aquagene breccias and massive effusives.

Massive lava flows, except for their greater abundance of amygdules, are not readily distinguished from feeder dykes and sills. The only sedimentary rocks assigned to the formation are a few small lenses of limestone and thin tephra beds. Maximum thickness of the formation is estimated to be at least 300 metres.

The Noel Formation is typically a discontinuous thinly bedded black argillite and siltstone unit with a few thin zones of dark grey limestone. In the type area on Noel Creek, the formation rests directly on Fergusson chert but nearby it overlies Pioneer greenstones. In the thermal aureoles of the major igneous intrusions, pyrite and andalusite are common secondary minerals developed in the argillaceous facies. Where best developed, the Noel Formation does not appear to exceed 800 metres in thickness and in some sections of the Cadwallader Group the unit is evidently missing.

The Hurley Formation is best exposed in the vicinity of Eldorado Creek in the northwest part of the map area. The predominant composition of these rocks is green, brown and black argillite and cherty argillite. These southwesterly dipping beds (Figure 2-2-4) are locally intercalated with gritty siltstones and sandstones and some calcarenites. At least two limestone marker horizons have been noted midway through the section. Coarse volcanic breccias of dacitic and basaltic composition occur in the upper part of the formation. Boulder and pebble conglomerate has been observed at the base of the formation, resting conformably on thin volcaniclastic beds and pillow lavas of the Pioneer Formation. Conglomerate with limestone clasts is also found above and lateral to the limestone members. Chert from the Fergusson Group is a common clast in the coarse Hurley sedimentary rocks, as are fragments of rhyolite quartz porphyry from an uncertain source. Pebbles of basic volcanic rock, schist and diorite are less common. The thickness of the Hurley Formation is estimated to be in the order of 1200 metres.

The Taylor Creek Group, as examined in the type area in the Taylor Creek basin, consists mostly of coarse clastic sedimentary rocks having an aggregate thickness of about 3000 metres. At the base and middle is a sequence of polymictic pebble and boulder conglomerate beds, each 10 to 15 metres thick, separated by siltstone seams, 1 to 2 metres thick. Above this are sandstones with

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British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

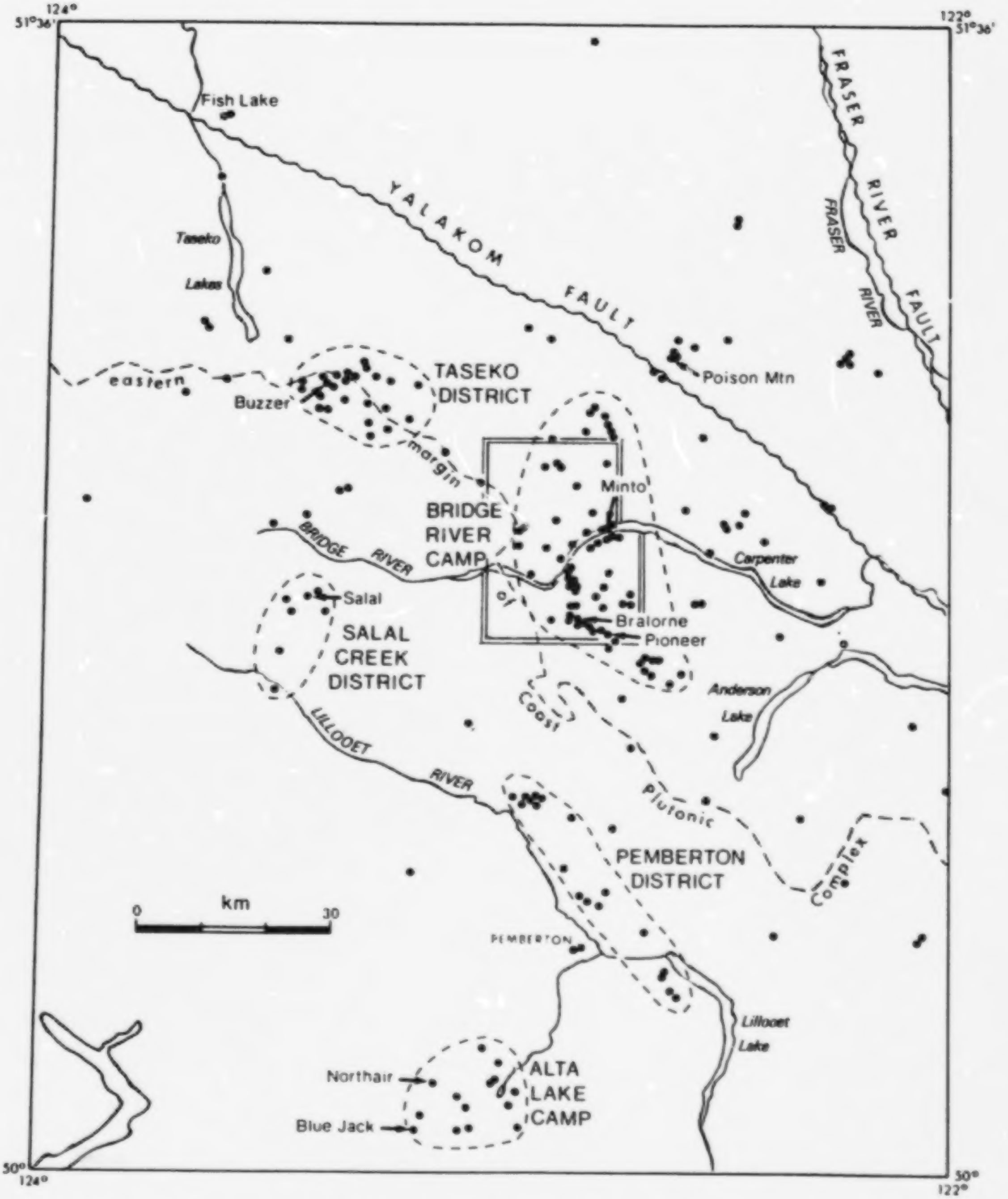
124°
51°36'
122°
51°36'
Fish Lake
YALAKOM
FAULT
FRASER
RIVER
FAULT
FRASER
RIVER
Taseko
Lakes
TASEKO
DISTRICT
Buzzer
Poison Mtn
eastern
margin
of
Coast
Plutonic
Complex
BRIDGE
RIVER
CAMP
Minto
BRIDGE
RIVER
Carpenter
Lake
Salal
SALAL
CREEK
DISTRICT
Bralorne
Pioneer
Anderson
Lake
LILLOOET
RIVER
PEMBERTON
DISTRICT
0
km
30
PEMBERTON
Lillooet
Lake
Northair
Blue Jack
ALTA
LAKE
CAMP
50°
124°
50°
122°

Figure 2-2-1. Location of 1:20 000-scale 1986 mapping (double frame) in Bridge River mining camp; mineral deposits shown as dots (after Woodsworth, Pearson and Sinclair, 1977).

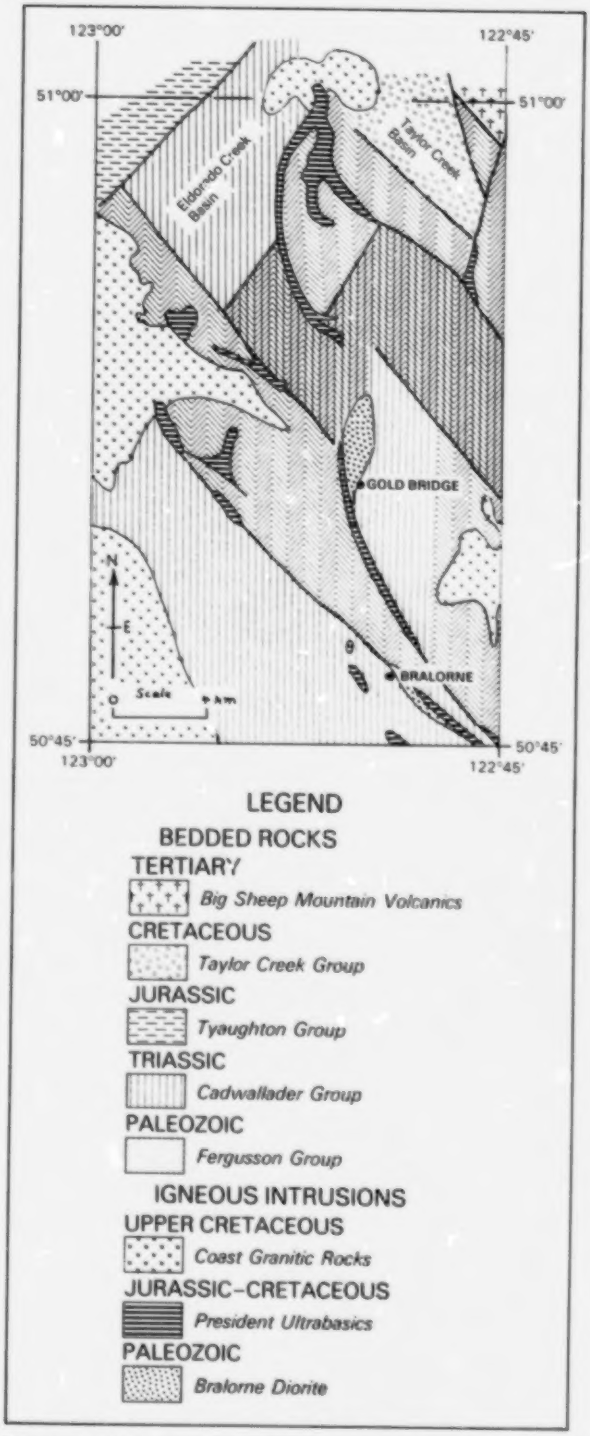
123°00'
122°45'
51°00'
51°00'
Eldorado Creek Basin
Taylor Creek Basin
GOLD BRIDGE
BRALORNE
N
E
0 Scale 5 km
50°45'
50°45'
123°00'
122°45'
LEGEND
BEDDED ROCKS
TERTIARY
Big Sheep Mountain Volcanics
CRETACEOUS
Taylor Creek Group
JURASSIC
Tyaughton Group
TRIASSIC
Cadwallader Group
PALEOZOIC
Fergusson Group
IGNEOUS INTRUSIONS
UPPER CRETACEOUS
Coast Granitic Rocks
JURASSIC-CRETACEOUS
President Ultrabasics
PALEOZOIC
Bralorne Diorite

Figure 2-2-2. Generalized geology of the Gold Bridge area (92J/15W).

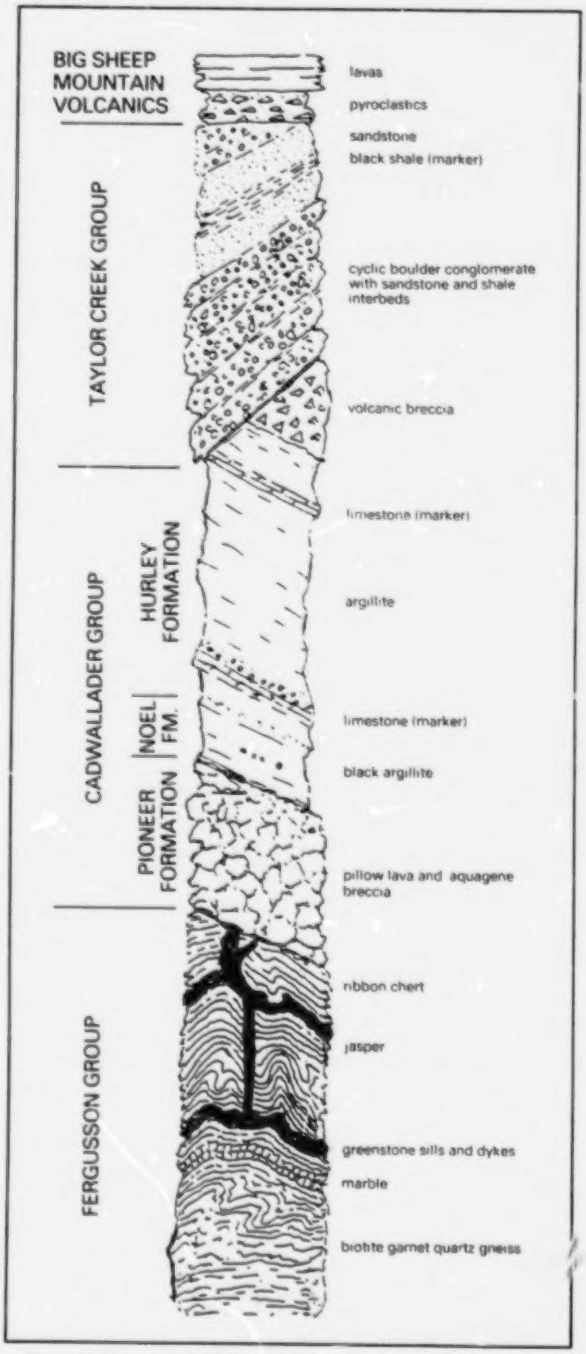
BIG SHEEP MOUNTAIN VOLCANICS
TAYLOR CREEK GROUP
CADWALLADER GROUP
HURLEY FORMATION
NOEL FM.
PIONEER FORMATION
FERGUSSON GROUP
lavas
pyroclastics
sandstone
black shale (marker)
cyclic boulder conglomerate with sandstone and shale interbeds
volcanic breccia
limestone (marker)
argillite
limestone (marker)
black argillite
pillow lava and aquagene breccia
ribbon chert
jasper
greenstone sills and dykes
marble
biotite garnet quartz gneiss

Figure 2-2-3. Stratigraphy in the Gold Bridge mining camp.

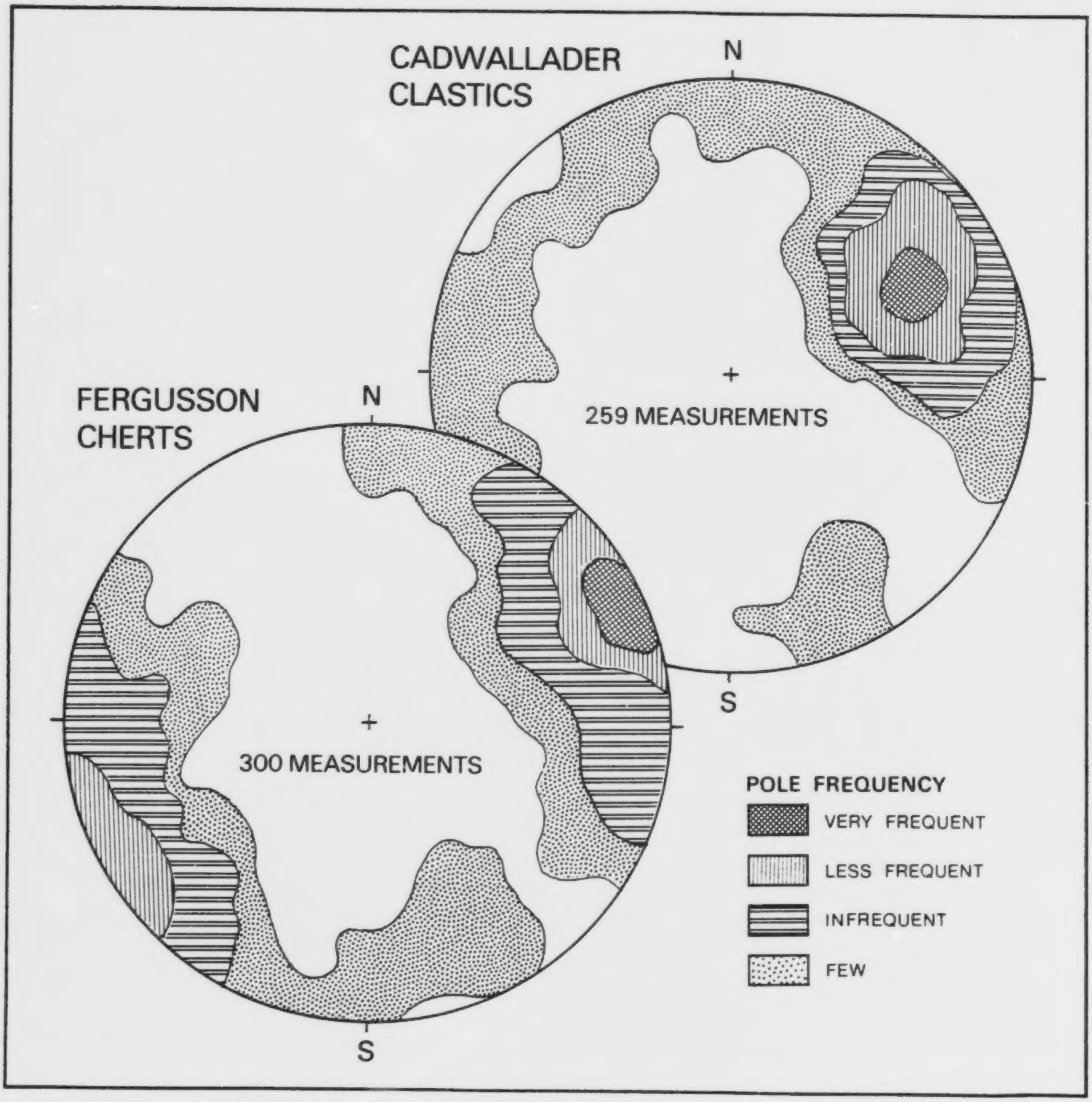

Figure 2-2-4. Equal area plots of bedding attitudes of Fergusson and Cadwallader Group rocks in the Gold Bridge area.

silty and conglomeratic interlayers, 600 metres thick, and a dark grey argillite marker zone, about 50 metres thick. Chert predominates among the clasts in the conglomerate, although porphyry, quartz, shale, limonite, conglomerate and limestone rock types are also present. The source of these fragments is believed to be the Fergusson Group and Hurley Formation.

The Big Sheep Mountain volcanics is an informal name applied to a small area of Tertiary andesitic lava and tuff breccia occurring in the extreme northeast corner of the map area. Little is known about the structure and petrography of these rocks. The cream and brown-coloured assemblage appears to be downfaulted in a small northerly trending graben. Petrological and age correlation with Tertiary dykes elsewhere in the map area is a possibility.

IGNEOUS INTRUSIONS

The main igneous intrusions are the Bralorne diorite (Paleozoic), the President ultrabasic rocks and the Coast plutonic rocks (Mesozoic). In addition there is a variety of small felsic to basic Mesozoic and Tertiary dykes and sills scattered across the map area.

The Bralorne diorite is exposed at intervals from the Pacific Eastern property near the southeast extremity of the map area, through the Bralorne-Pioneer mineral belt, to the town of Gold Bridge on the Carpenter Lake Highway. The alignment and elongated shape of these bodies suggest emplacement of the diorite in a major fault zone. The diorite is a mottled greenish-grey rock with a variable texture usually characterized by a reticulate pattern of light-

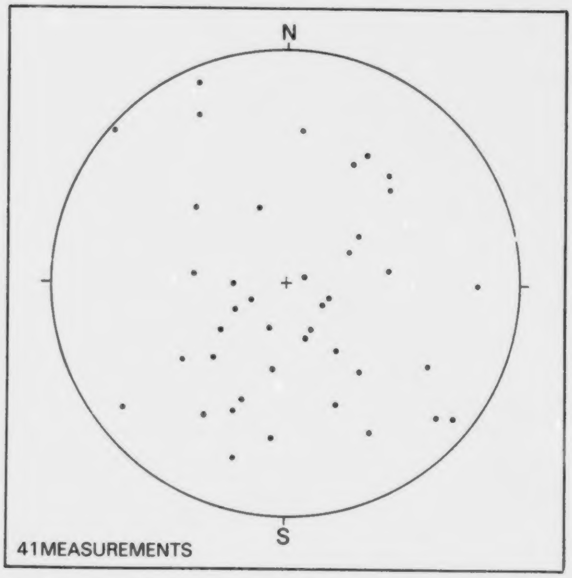

Figure 2-2-5. Stereographic plot of fold axes for Fergusson chert beds in the Gold Bridge area.

coloured veinlets of felsic minerals; epidote, prehnite and calcite. In thin section a typical sample is found to consist of about equal amounts of amphibole and plagioclase. According to the mineralogical scheme of rock classification, the name diorite has been applied because of the sodic composition of the plagioclase, although the chemical composition of these rocks ranges to gabbro. Potassium-argon analyses, performed at The University of British Columbia on a sample of the diorite from Gold Bridge, yielded an Upper Carboniferous age.

The President ultrabasic rocks are lenticular bodies that follow the belt of the Bralorne diorite. Other major elongated zones of ultrabasic rocks occur along major faults on Mount Penrose and in the area between the Eldorado Creek and Taylor Creek basins. Although much of the rock has been converted to serpentine, numerous textural phases are seen in outcrop. These range from bright green schistose phases and dull black massive varieties to porphyritic serpentine with phenocrysts of bastite. In the Eldorado and Taylor Creek basins, the serpentine zones are commonly accompanied by bright rust-coloured carbonate bands known as "listwanites". The origin of these ultrabasic rocks is thought to be solid emplacement of pyroxenite and dunites in fault zones followed by extensive metasomatism. The age of the ultrabasic intrusions is known to be younger than the Upper Triassic Hurley sedimentary rocks that they cut, and older than the overlying Middle Cretaceous (Albian) Taylor Creek beds.

The Coast plutonic rocks comprise an assortment of granitic plutons exposed mainly in the southwest and west part of the map area in the vicinity of Mount Sloan, Mount Dickson and the westerly ridges of Mount Penrose. Other related, but isolated stocks, occur on Mount Eldorado on the north boundary of the map area and in the Bendor Range on the southeast boundary. These rocks are mostly hornblende granodiorite with accessory biotite and sphene found in some samples. Quartz diorite and biotite granite are local phases within the larger granodiorite intrusions. Apophyses of "soda granite" occur associated with the quartz veins in the Bralorne-Gold Bridge belt. The age range for these intrusions is Upper Cretaceous (~80 million years) to Lower Tertiary (58.9 million years), the Bendor stock being the youngest.

Numerous Mesozoic and Tertiary dykes and sills occur throughout the map area. Dyke swarms of basic to intermediate composition (greenstones), conspicuous in the Fergusson chert assemblage, are thought to be feeders to the Triassic volcanic rocks. They are commonly fine-grained and massive and less deformed than the adjacent host rocks. The Tertiary dykes and sills are generally fresh and undeformed, although alteration may be pronounced in some mineralized zones (that is, carbonated dykes). The main Tertiary effusives are light brown feldspar porphyries and fine-grained pulaskite equivalents, grey and brown hornblende andesite porphyries and, less commonly, fresh basalt dykes. Some of these rocks form small plugs and volcanic necks.

STRUCTURAL GEOLOGY

The structural history of the Bridge River mining camp records repeated cycles of folding and faulting. The total effect of this is displayed in the rocks of the Fergusson Group, which are the oldest in the area. These rocks are steeply dipping and intricately folded. The lack of any apparent consistency in the direction of fold axes across the region (Figure 2-2-5) is evidently due to localization of structures because of (1) the presence of primary slump folding, (2) deformation at the irregular margins of the granitic plutons and (3) rotation of beds by repeated episodes of faulting. The Hurley beds, recording only part of this history, are more simply deformed; only two periods of folding have been identified.

The major fault lineaments, marking the boundaries of the principal structural domains, commonly coincide with the zones of ultramafic rocks which are readily mapped. These boundaries, which trend north and northwest, have sustained through the emplacement of the Upper Cretaceous-Tertiary granitic plutons. The north-trending boundaries appear to be tension faults separating horst and graben panels in the northern part of the map area; the northwest trend is the principal shear direction in a regional stress scheme.

MINERALIZATION

The Bridge River mining camp remains foremost in total gold production in British Columbia. Only five of the 73 properties in the camp achieved significant production. The statistics are as follows:

TABLE 2-2-1
PRODUCTION FROM THE BRIDGE RIVER CAMP

	Tonnes	Gold (kg)	Silver (kg)	Copper (kg)	Lead (kg)	Zinc (kg)
Congress	943	2.5	1.3	38	—	—
Wayside	36 977	166.0	26.0	—	—	—
Minto	79 073	546.0	1 573.0	9 673	56 435	—
Pioneer	2 240 552	41 475.0	7 611.0	—	59	139
Bralorne	4 954 473	87 759.0	21 969.0	—	157	—

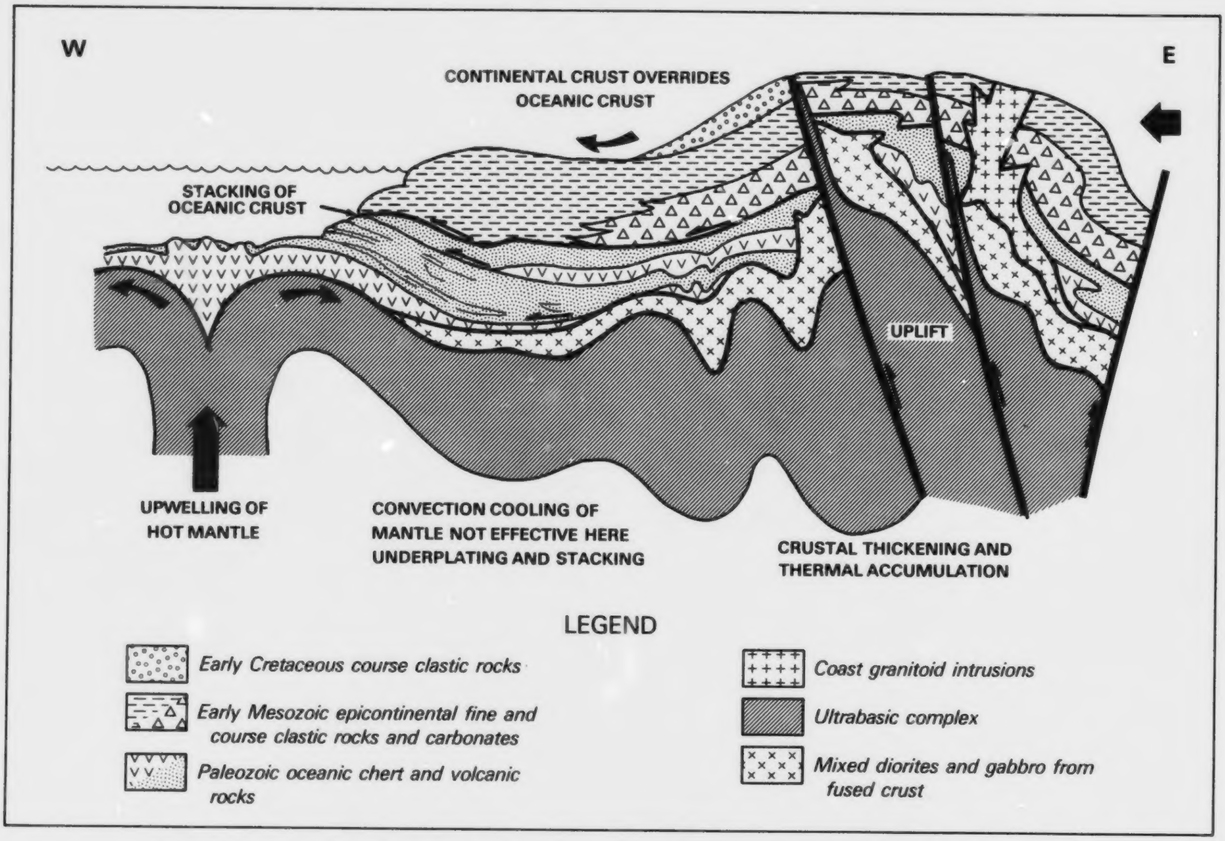
W
E
CONTINENTAL CRUST OVERRIDES OCEANIC CRUST
STACKING OF OCEANIC CRUST
UPLIFT
UPWELLING OF HOT MANTLE
CONVECTION COOLING OF MANTLE NOT EFFECTIVE HERE UNDERPLATING AND STACKING
CRUSTAL THICKENING AND THERMAL ACCUMULATION
LEGEND
Early Cretaceous course clastic rocks
Early Mesozoic epicontinental fine and course clastic rocks and carbonates
Paleozoic oceanic chert and volcanic rocks
Coast granitoid intrusions
Ultrabasic complex
Mixed diorites and gabbro from fused crust

Figure 2-2-6. Tectonic model for Early Cretaceous events in southwestern and interior British Columbia.

It has been proposed that the extensive fissure system in the camp provided the necessary channelways for vein-forming and mineral-bearing solutions. In this model the Coast granitic intrusions served as the heat and water source and possible origin of the metals. This concept is supported by a 35-kilometre-wide zonation of deposits developed lateral to the Coast plutons (Woodsworth *et al.*, 1977). Close to the Coast plutons ores tend to be arsenic rich, passing outwards through an antimony zone to deposits enriched in mercury.

Examples of proximal to distal deposits are the Bralorne, Pioneer and Congress mines, and the Lillomer prospect respectively.

At the Bralorne and Pioneer mines the gold and arsenopyrite-bearing quartz veins fill en echelon tension fractures in the Bralorne diorite and Pioneer greenstones. The source of these veins and the associated carbonate alteration appears to be the apophyses and cupolas of the soda granite.

At the Congress mine mineralization is characterized by an abundance of stibnite, arsenopyrite and some cinnabar associated with ankeritic alteration and quartz lenses in shears. The host rocks include fissured Tertiary porphyry dykes. The deposit is distal to local granitic intrusions.

The Lillomer mercury prospect is located on North Cinnabar ridge remote from the Coast Plutonic Belt. Cinnabar and native mercury occur with calcite in a fissure system near the contact of the Fergusson and Cadwallader Groups.

It has been noted that the veins in the mines of the area were often abnormally rich adjacent to the ultrabasic rocks. Consequently it can be argued that the ultimate source of gold is related to deep fissures along which the ultrabasic rocks were intruded. The rise of ultrabasic mantle material may coincide with underplating and stacking of oceanic and mantle slabs beneath an overriding continental plate (Figure 2-2-6). The subsequent intrusion of granitic plutons could have caused redistribution of metals already introduced on the major faults.

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THE PACIFIC EASTERN GOLD PROSPECT
PIONEER EXTENSION PROPERTY
LILLOOET MINING DIVISION
(92J/15)

By B. N. Church

INTRODUCTION

The Pacific Eastern property (MI 092J/NE-009) is centred at latitude 50°45′ north, longitude 122°45′ west, 5.5 kilometres southeast of the Bralorne mine, approximately 170 kilometres north of Vancouver. Access is by gravel road 12.4 kilometres southeast from the town of Gold Bridge (Figure 2-3-1).

The property consists of 88 Crown-granted mineral claims and fractions including the Pioneer Extension, President, Plutus and Dan Tucker claim groups. Current exploration is focused on the Pioneer Extension ground.

The writer visited the property in August 1986 and logged core from recently completed diamond drilling. Much appreciation is owed to Messrs. Gary Nordine and George Norman of Normine Resources Ltd. and Bema Industries Ltd. for access to the property and company information.

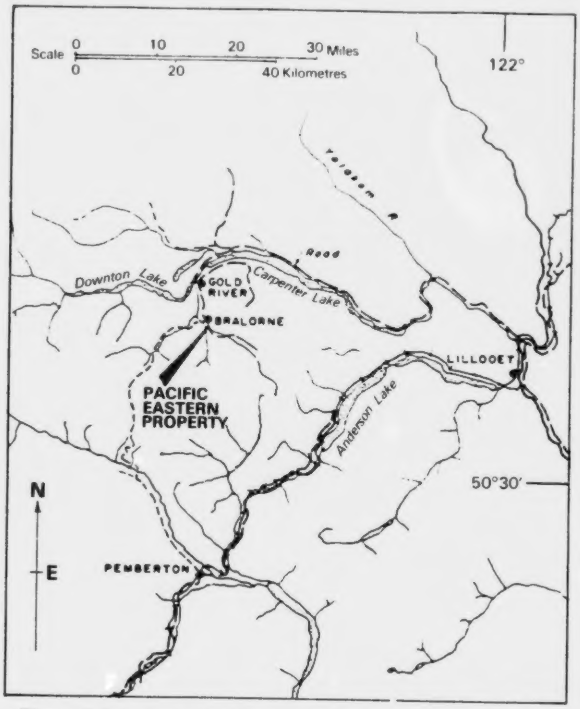

Figure 2-3-1. Location Map, Pacific Eastern Gold prospect.

EXPLORATION AND DEVELOPMENT HISTORY

Placer gold was first discovered on the lower course of the Hurley River prior to 1860. By 1865 its source had been traced to quartz veins exposed on the slopes above Cadwallader Creek.

The area became famous following development of the Bralorne and Pioneer mines. This operation, in continuous production from 1928 to 1971, achieved the status of the largest gold producer in British Columbia, yielding 174 900 kilograms of gold and 40 000 kilograms of silver from 7.21 million tonnes of ore milled. Recent estimates by E&B Exploration Inc. indicate that 740 275 tonnes grading 8.9 grams per tonne gold remain in the Bralorne mine above the 2600 level.

Pacific Eastern Gold Mines Ltd. was formed in 1929 to explore the Pioneer Extension claim group adjoining the Pioneer mine on the southeast. In addition to much surface work and drilling, extensive underground tunnelling was completed between 1935 and 1937. Mine development during this period included the Pioneer Extension adit, driven 200 metres from the slopes north of Cadwallader Creek and an internal shaft, 160 metres deep, connected to the 520 level crosscut which was driven southerly 1300 metres under the valley of Cadwallader Creek. From the 520 level crosscut the 1595 drift system was driven 525 metres easterly and a winze, 70 metres deep, sunk near the west end to link the 1595 drift with several short tunnels on the 690 level (Figure 2-3-2).

Exploration was resumed in 1945 to 1947, following a period of dormancy. Several new veins were discovered by diamond drilling and subsequently tested by extension of the 1595 drift to the east.

Ownership of the claims subsequently passed from Noranda Mines Ltd. (1947-1973) to R.J. Barclay (1973-74) and later to J.T.M. Enterprises Ltd. and B.R.H. Investments Ltd. of Vancouver. In May 1983 the property was optioned by Normine Resources Ltd.

Work by Normine Resources confirms the continuation of lithology and structure from the Bralorne-Pioneer mines through the Pioneer Extension claim group. Three deep diamond-drill holes 85-2, 85-3 and 86-1 (to 855, 710 and 762 metres respectively), prove the presence of quartz veins and associated carbonate alteration typical of production zones in the nearby mines.

GEOLOGICAL SETTING

Exploration on the Pioneer Extension claims is focused on a segment of a 2-kilometre-wide, east by southeast-trending belt of metasedimentary, metavolcanic and intrusive rocks. The mine workings and the three long diamond-drill holes directed across the belt provide a good view of lithologies and structures (Figure 2-3-2).

The principal lithological units are Paleozoic chert beds of the Fergusson Group and downfaulted Triassic greenstones (Pioneer Formation) and metasedimentary rocks (Noel and Hurley Formations) of the Cadwallader Group. Structural relationships are complicated by the emplacement of diorite and granite bodies (the Bralorne intrusions), ultrabasic rocks (President intrusions) and younger hornblende and feldspar porphyry dykes. The major intrusions are elongated subparallel to the trend of the belt and concordant with the principal formations, following the course of the main faults.

Diamond-drill holes north of Cadwallader Creek are collared in Fergusson chert. These rocks are separated from the Cadwallader formations by a steeply dipping ultrabasic body and the Fergusson fault. Repeated intercepts of Triassic greenstones and metasediments suggest that these rocks are tightly folded, but this is not proved by the internal structural relationships.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

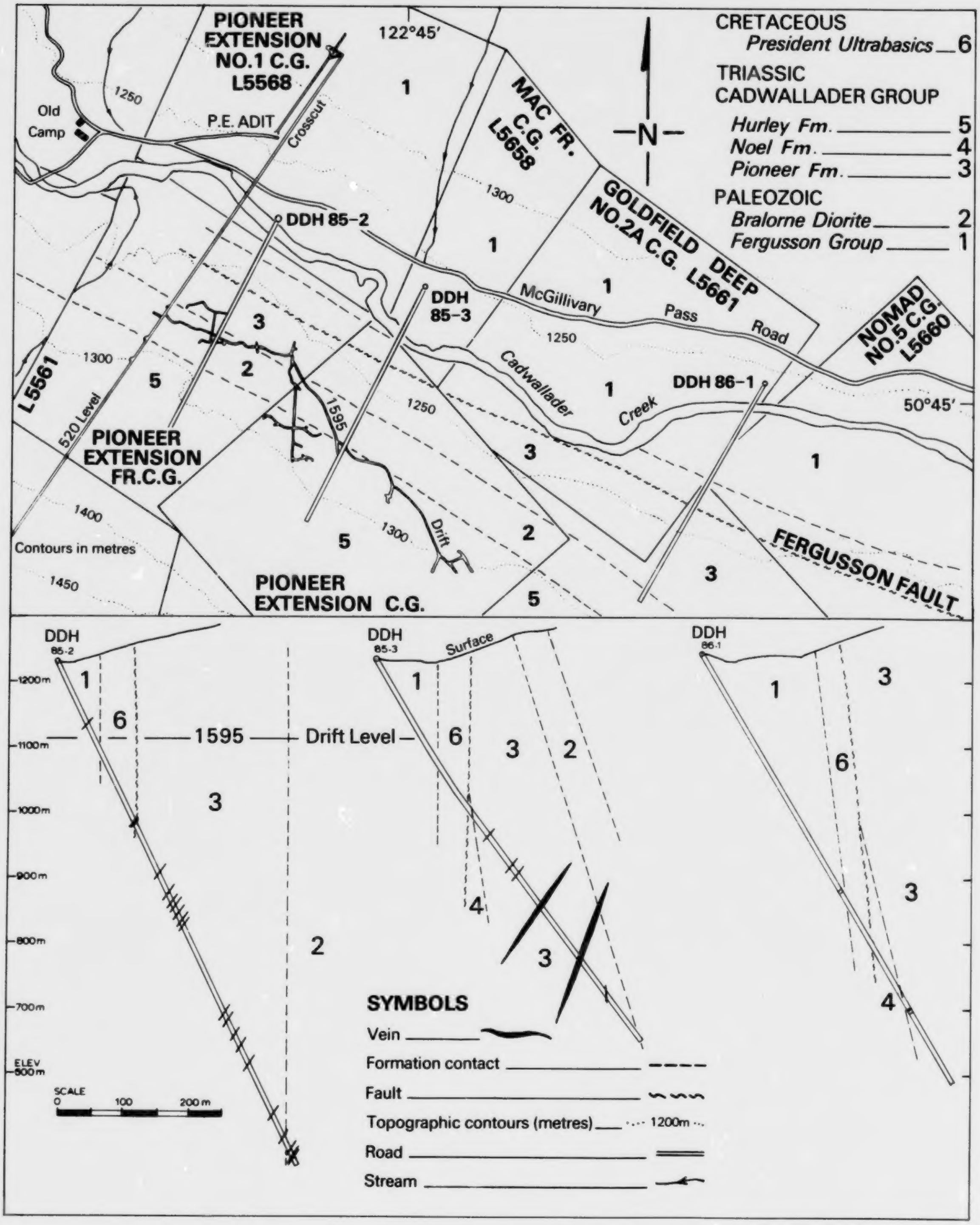
PIONEER EXTENSION NO.1 C.G. L5568
122°45′
CRETACEOUS
President Ultrabasics 6
TRIASSIC
CADWALLADER GROUP
Hurley Fm. 5
Noel Fm. 4
Pioneer Fm. 3
PALEOZOIC
Bralorne Diorite 2
Fergusson Group 1
N
Old Camp
1250
P.E. ADIT
Crosscut
MAC FR. C.G. L5658
GOLDFIELD DEEP NO.2A C.G. L5661
1300
DDH 85-2
DDH 85-3
McGillivary Pass Road
NOMAD NO.5 C.G. L5660
L5561
1300
1250
Cadwallader Creek
DDH 86-1
50°45′
1595
520 Level
PIONEER EXTENSION FR.C.G.
1250
1400
1300
Drift
Contours in metres
1450
PIONEER EXTENSION C.G.
FERGUSSON FAULT
1
2
3
5
DDH 85-2
DDH 85-3
DDH 86-1
Surface
1200m
1100m
1000m
900m
800m
700m
ELEV 600m
1595 Drift Level
6
4
SCALE 0 100 200m
SYMBOLS
Vein
Formation contact
Fault
Topographic contours (metres) 1200m
Road
Stream

Figure 2-3-2. Geology and diamond-drill hole sections, Pioneer Extension property.

MINERALIZATION

Typical mineralization in the Bralorne-Pioneer camp consists of free gold with pyrite and arsenopyrite (1 to 3 per cent) in banded quartz veins. Veins average 1 to 2 metres wide with strike length and down dip extent ranging from 100 to 1500 metres. Most veins are gashes developed by repeated fracturing of the competent greenstones and crystalline plutonic rocks lying between the Fergusson fault and other subsidiary rifts in the Cadwallader fault system. Extensive hydrothermal carbonate alteration envelopes, up to 70 metres wide, accompany and appear to slightly postdate many of the quartz veins.

Two mineralized zones were opened up by the Pacific Eastern underground workings in previous exploration programs. These are (1) a quartz vein in the west drift (690 level), located 370 metres south of the Pioneer Extension portal and (2) two quartz veins intercepted by drilling from the 1595 drift near the eastern extremity of the mine, 775 metres southeast of the Pioneer Extension portal. According to company reports, the vein in the west drift is 29 metres long, 0.3 metre wide and averages 19.8 grams per tonne gold. The veins near the southeast end of the 1595 drift are 1.0 to 1.5 metres wide and contain visible gold; complete assay results are not available. They appear to be en échelon or continuous with two quartz veins, 1.2 and 1.5 metres wide, intersected in diamond-drill hole 85-2 within a wide zone of intense carbonate and biotite alteration.

The age of mineralization is estimated to range from Upper Cretaceous to Lower Tertiary, the interval between emplacement of the Bendor granodiorite stock and the unaltered crosscutting Tertiary dykes. In a few instances late growth of stibnite has been observed in small fissures in the dykes.

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THE BRALORNE GOLD VEIN DEPOSIT: AN UPDATE*
(92J/15)

By C. H. B. Leitch and C. I. Godwin
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The University of British Columbia

INTRODUCTION

Fieldwork on the Bralorne gold vein deposit in 1986 included further logging of core drilled from the surface by Mascot Gold Mines Limited in 1980 to 1984 and revisions to the surface and underground geology. Unfortunately most of the underground core from the days of the Bralorne mine operation was destroyed this summer. The geology of the lower levels of the mine, from 8 to 44, can no longer be studied in detail. However several key intersections of the main 77 and 79 vein systems and their wallrocks, saved in 1985, are available for studies of alteration, ore mineralogy and fluid inclusions. Preliminary potassium-argon dates have also been completed.

REVISED GEOLOGY

The geology of the northeastern flank of the Bralorne intrusive complex is much more complex than was previously suspected from surface mapping of limited outcrops, nevertheless the rock units are as described in Leitch and Godwin (1986) with the minor exceptions noted below.

Soda granite forms a large northwest-trending dyke-like intrusive (3 kilometres long by 200 metres wide) in contact with diorite on the southwest and andesites of the Cadwallader Group on the northeast. This area was previously mapped as underlain by sediments of the Hurley Formation.

Long sections (in the order of hundreds of metres) of apparently volcaniclastic sediments, intercalated with argillite in a turbidite sequence, were cut by drill holes on the northeastern flank of the dyke. Similar sections are exposed in the gorge of Cadwallader Creek immediately east of Bralorne townsite.

All units, including the Bridge River Group cherty sediments, are cut by a large number and variety of dykes. In order of increasing age, these are: lamprophyre; green hornblende porphyry; albitite; and a previously unrecognized grey plagioclase porphyry that is intermediate in texture and time of formation to the soda granite and albitites. It is also apparent from logging the inclined surface drill holes that most structural features (dykes, veins, intrusive contacts) have subparallel dips of about 65 degrees northeast. The only exceptions are very late lamprophyre dykes which appear to dip vertically and strike due north. Dykes of albitite and the sparsely developed grey plagioclase porphyry strike about 115 degrees, parallel to the structural grain of the district. The later green hornblende porphyry dykes fill a set of conjugate fractures with one direction parallel to the strike of the older dykes.

Petrographic study of the dykes and relogging of all dyke intersections in core suggest that rather than two distinctly separate dyke sets (albitite and green hornblende porphyry) there may be considerable overlap between the two. The end members are clearly distinguishable (*see* chemistry in Tables 2-4-1 and 2-4-2) but there are many examples of fine-grained green dykes which could be either relatively late, unaltered albitites or rather chilled, thin, hornblende porphyry dykes. Ragged chlorite-calcite pseudomorphs after hornblende phenocrysts are detectable in all of the albitite dyke sections studied. In addition, although the green hornblende porphyry dykes are usually quite unaltered, a dyke with abundant relict hornblende phenocrysts is strongly altered adjacent to the 51 vein (*see* Figure 47-2, Leitch and Godwin, 1986).

GEOCHRONOLOGY

Distinguishing the relative ages of the dyke sets is important in establishing the chronology of events in the camp. Two potassium-argon dates obtained recently indicate a surprisingly large interval between intrusion of the main quartz diorite mass (about 225 ± 10 million years) and the largely postmineral green hornblende porphyry dyke set (85.7 ± 3 million years). Both dates are on hornblende concentrates that have apparently not been significantly reset by Coast Plutonic Complex activity. Considerable confidence can be placed in the later date, as the hornblende contained 0.14 per cent potassium. The potassium content of the hornblende in the diorite was too low (0.06 per cent) for an accurate age determination to be made. Reduction of the data obtained gives an age of 284 million years, but J. Harakal (personal communication, 1986) feels this is likely a maximum as excess argon commonly has a more noticeable effect in low-potassium rocks. Conodonts show that the Cadwallader Group, intruded by the diorite, is Carnian/Norian in age (225 million years) (Rusmore, 1985) so the diorite is likely 220 to 200 million years.

Unfortunately no hornblende or biotite is available from the andesites, soda granite, grey plagioclase porphyry, or albitite, but biotite phenocrysts in the lamprophyre will be dated. Zircons for uranium-lead dating were not recovered from two large samples of the Pioneer andesites. However a rubidium-strontium treatment of the Bralorne intrusive suite and the andesites is in progress. Zircons were recovered from each of two samples of the diorite and the soda granite and from one sample of the albitite dykes, but these are awaiting analysis. When available, these dates will help to elucidate the timing of intrusion and mineralization. An unsuccessful attempt has been made to date limestone lenses in the Hurley Formation cored by Normine Resources Ltd. on the P.E. Gold prospect adjoining the Pioneer mine. Samples analysed by the Geological Survey of Canada are barren of conodonts.

PETROLOGY

Preliminary chemical data for a limited suite of major rock units is set out in Table 2-4-1. A noteworthy feature in the major element chemistry is the extremely low K_2O in all igneous rocks of the Bralorne area, ranging from 0.08 per cent in the diorite to 0.69 per cent in soda granite (the only exception is 2.5 per cent K_2O in a sericite-altered albitite dyke). The relatively high Na_2O (up to almost 6 per cent) is also of interest and corroborates the albitic plagioclase (An_{0-10}, rarely to An_{15}) which is present in all units, including even the hornblendites, pyroxenites, and Pioneer andesites. This albite may be a reflection of regional greenschist metamorphism (widespread chlorite and actinolite, especially in the

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

andesites, also suggest this), or may be due to widespread hydrothermal alteration. Obvious albitization textures (Leitch, 1981) indicative of hydrothermal alteration are limited to margins of some veins and are rarely pervasive. However, it is possible that the much more obvious feldspar-destructive alteration (epidote, chlorite, carbonate, sericite and quartz, moving progressively closer to the vein) has obscured earlier alteration. Altered rocks show a strong increase in CaO and loss-on-ignition toward the vein, corroborating the carbonate alteration; increases of K_2O to 2 to 3 per cent probably correlate with the sericitic alteration, while the drop in Na_2O (to near zero) and Fe_2O_3 (by half) indicates the destruction of original albite and hornblende.

The relationship of diorite intruding ultramafics, postulated last year (Leitch and Godwin, 1986) has been confirmed. The gradual transition from normal diorite (about 40 per cent mafics) to hornblendite (60 to 80 per cent mafics) to relict pyroxenite/peridotite with hornblende mantling clino and orthopyroxene is suggestive of border phase contamination of the diorite by the ultramafic to produce much of the hornblendite commonly seen along its southwestern flank (modes estimated from thin-section studies, Table 2-4-2). Dyking of both diorite and soda granite into hornblendite and serpentinite supports this conclusion.

The relationship between diorite and soda granite is not as clear. Partial melting or differentiation of the diorite have been proposed as alternative mechanisms for the formation of the soda granite. They cannot be distinguished petrologically using addition-subtraction diagrams of Bowen (1956) or a plot of normative Qz-Or-Ab. However a few observations may be made. The temperature required to partially melt a rock of diorite composition, which lies far from the granite minimum, would be 1050°C if no volatiles were present, or perhaps as low as 750°C in the presence of abundant H_2O and HCl (Mehnert, 1971). This is far above the 400 to 410°C (Winkler, 1967) attested to by the adjacent lower greenschist facies rocks. Also, although it is clear that the contact zone between diorite and soda granite is unquestionably a migmatite (variety agmatite, Mehnert, 1971) the texture is due to injection of soda granite into diorite. The relationship is partly obscured by dark andesite xenoliths included in diorite prior to intrusion of the soda granite, and is therefore not clear in drill core, but can clearly be seen in an excellent outcrop near the bridge at Goldbridge. It is possible that

TABLE 2-4-1
CHEMISTRY OF MAJOR UNITS IN THE BRALORNE-PIONEER AREA

Sample No. **(N)**	**CO95** **(3)**	**CO93** **(3)**	**CO82B** **(2)**	**AVGDI** **(8)**	**CO94** **(3)**	**CO82A** **(2)**	**AVGSG** **(5)**	**CO92** **(3)**	**CO83** **(3)**	**RESTI** **(CALC)**
Major Elements (%)										
SiO_2	47.50	59.35	55.52	55.32	71.83	66.10	68.90	64.54	52.25	56.1
Al_2O_3	12.95	11.22	13.60	13.12	13.68	14.27	13.97	17.76	14.56	10.6
TiO_2	0.95	0.23	0.50	0.40	0.19	0.20	0.20	0.20	0.77	0.3
Fe_2O_3 (Total Fe)	10.55	7.80	9.65	9.28	3.07	4.74	3.88	2.83	10.24	9.0
MgO	12.54	8.12	5.07	7.00	0.44	1.61	1.03	1.11	6.48	10.2
CaO	9.36	7.06	5.89	7.02	2.10	4.00	3.06	3.76	8.69	8.4
Na_2O	1.47	3.88	4.71	3.60	5.60	6.00	5.78	1.98	3.10	3.4
K_2O	0.04	0.14	0.10	0.08	0.69	0.12	0.41	2.67	0.25	0.0
MnO	0.28	0.16	0.18	0.20	0.08	0.09	0.08	0.11	0.19	0.2
P_2O_5	0.11	0.02	0.02	0.03	0.05	0.11	0.07	0.12	0.19	0.0
LOI	4.71	1.82	3.96	2.71	2.47	2.30	2.40	4.73	2.78	1.6
Total	99.96	99.80	99.20	98.76	100.20	99.54	99.78	99.81	99.50	99.8
Minor Elements (ppm)										
As	14	1	6	8	12	8	10	11	3	
Ba	50	47	120	63	102	120	110	706	245	
Cl	26	74	53	52	28	33	30	14	57	n
Co	30	32	24	30	4	16	13	9	35	o
Cr	275	160	35	86	10	26	17	12	135	t
Cu	75	62	69	60	11	18	14	6	36	
Mo	1	0	2	1	1	2	1	1	2	a
Nb	3	1	2	1	2	0	1	2	1	n
Ni	70	69	17	43	3	4	3	2	36	a
Pb	6	6	8	8	6	7	7	9	4	l
Rb	2	3	4	3	14	3	9	39	5	y
S	745	430	6000	375	760	4160	760	950	310	s
Sb	3	2	0	2	2	3	2	2	1	e
Sr	270	110	190	125	80	235	80	110	350	d
V	270	145	200	180	14	58	30	29	230	
Y	22	16	20	17	17	6	12	10	22	
Zn	105	56	65	64	36	54	43	52	100	
Zr	63	49	34	40	86	24	60	69	61	

(N) is number of analyses; 5 separate rocks for average diorite, 2 for soda granite.

Sample identifications: CO95 = Pioneer andesite; CO93 = Bralorne quartz diorite; CO82B = same; AVGDI = average of five diorites, 16 Level to surface; CO94 = soda granite; CO82A = same; AVGSG = average of two soda granites; CO92 = albitite dyke, sericite-carbonate altered; CO83 = green hornblende porphyry dyke; RESTI = calculated restite composition.

TABLE 2-4-2
CIPW NORMS AND ESTIMATED MODES OF MAJOR UNITS FROM THE BRALORNE-PIONEER AREA

Sample No.	CO95	CO93	CO82B	AVGDI	CO94	CO82A	AVGSG	CO92	CO83	RESTI	HBITE	AVGAB	AVGGHO	LAMP
Normative Minerals														
Quartz		10.5	7.1	8.1	30.4	19.7	25.0	32.8	4.5	5.4				
Corundum					0.02			5.1						
Orthoclase	0.2	0.8	0.6	0.5	4.1	0.7	2.4	15.8	1.5	0.0				
Albite	12.4	32.8	39.9	30.5	47.4	50.8	48.9	16.8	26.2	28.8			(no analyses available)	
Anorthite	28.6	12.8	15.7	19.4	10.1	11.6	11.0	17.9	25.8	13.6				
Diopside	13.7	17.8	10.9	12.3		6.2	3.1		13.1	22.4				
Hypersthene	32.5	19.0	14.7	20.0	3.8	5.2	4.5	4.0	19.6	23.1				
Olivine	2.0													
Magnetite	3.7	3.8	5.4	4.5	1.5	2.3	1.9	2.1	4.3	4.3				
Ilmenite	1.8	0.4	0.9	0.8	0.4	0.4	0.4	0.4	1.5	0.6				
Apatite	0.3	0.04	0.04	0.1	0.1	0.3	0.2	0.3	0.5	0.02				
Differentiation Index	13	44	47	39	82	71	76	65	32	34				
Modes (Estimated Volume %)														
Quartz	10	10	6	11	40	20	37	40	10	0	1	26	8	0
Albite	40	40	60	55	50	70	52	55*	52	35	20	59	54	0
Mafic: (Hblend)		48	30	33	8	7	11	3	35	60	62	13	36	(BI = 25)
(Cpx)	55*										15			35
Ilmenite (Rut)	3	2	1	1	1	1	tr	1	3	5	2	1	2	2
Pyrite (Py/Po)	2	tr	3	tr	1	2	1	1	0	0	1	1	0	(AP = 3)
(No. of Samples)	(1)	(1)	(1)	(10)	(1)	(1)	(10)	(1)	(1)	(1)	(6)	(13)	(8)	(1)

* Sum of alteration products (chl, ep, carb for mafics; ser, carb for plagioclase). Sample identifications are as listed in Table 2-4-1, with the addition of HBITE (average hornblendite), AVGAB (average albitite dyke), AVGGHO (average green hornblende porphyry), and LAMP (lamprophyre dyke). Norms calculated with a BASIC program (FeO/Fe_2O_3 estimated for each rock).

the soda granite was derived from partial melting of the diorite at depth during a younger thermal event, but this hypothesis is only tenable if supported by zircon dating.

VEIN MINERALOGY

Very little sulphide, often only 1 to 3 per cent, is present in the veins. Altered wallrocks usually contain up to 5 or even 10 per cent sulphides over widths of a few centimetres to several metres. However the sulphide assemblage is similar in both veins and wallrocks with the exception of a few more diverse assemblages (*see* following) in veins with rich gold values. Arsenopyrite with lesser pyrite is ubiquitous. Occasionally pyrrhotite, almost always with chalcopyrite, is as abundant as the arsenopyrite. The high arsenic content of the system is noteworthy.

It is likely that rutile, also ubiquitous, is the product of hydrothermal alteration of ilmenite originally present in the intrusive host; this may indicate formation of some of the vein material by *in situ* replacement of wallrock.

Septae of wallrock within the veins are strongly replaced by sulphides and form thin dark bands parallel to the contacts, giving the veins their characteristic ribboned appearance. Usually the septae are strongly sheared and slickensided, but occasionally they are stylolitic, suggesting pressure solution. Textures in the vein quartz are strongly outlined by myriads of inclusions arranged in crystallographic growth zones. Quartz grains grew perpendicular to the walls of the veins, while sulphides are restricted to a "breccia network" of other gangue minerals interstitial to the quartz.

Free gold is relatively common in the polished sections studied, occurring as blebs 2 to 10 microns across and often in or associated with pyrite, tetrahedrite or arsenopyrite. Larger gold blebs (15 to 50 microns) are found in more diverse sulphide assemblages which may include galena, sphalerite, tetrahedrite, chalcopyrite, and possibly bournonite. Wherever fuchsite is found in the altered wallrock, a few grains of chromite are always present. The chrome is likely derived from picotite in inclusions of ultramafic material. Oxidation has produced limonite in some specimens.

Gold selenides and tellurides, stibnite, and marcasite, reported by Dolmage (1934) and Cairnes (1937), were not seen in this study. Dolmage's observations were confined to the Pioneer vein system which is no longer accessible.

FLUID INCLUSIONS

Preliminary fluid inclusion data (at levels 15 and 44 only and uncorrected for pressure) indicate a tendency toward higher homogenization temperatures and possibly higher salinities at depth. At both levels there appear to be primary and pseudo-secondary inclusions. Table 2-4-3 summarizes the data (n = number of measurements).

TABLE 2-4-3
FLUID INCLUSION DATA FROM BRALORNE MINE (in °C)

	Pseudosecondary		Primary	
	T melt	T hom	T melt	T hom
Level 15	−2	190	−3.5	260
(−500 m)	(n = 4)	(n = 5)	(n = 5)	(n = 20)
Level 44	−2	200	−5	315
(−1750 m)	(n = 24)	(n = 37)	(n = 8)	(n = 30)

ACKNOWLEDGMENTS

Thanks are extended to Mascot Gold Mines Limited for allowing completion of the core logging begun in 1985. The field support and encouragement provided by Brad Cooke of Levon Resources Ltd.

are greatly appreciated. Research at The University of British Columbia has been supported by grants from the British Columbia Ministry of Energy, Mines and Petroleum Resources and the Canada/British Columbia Mineral Development Agreement (MDA) program.

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THE BUBBLE HOTSPRING DEPOSIT
BLACK DOME AREA
(92O/8W)

By B. N. Church

INTRODUCTION

The Bubble Hotspring deposit occurs on the Bubble claim group owned by Malabar Mines Ltd. The deposit is readily accessible on the old Porcupine Creek road 2.5 kilometres east of Black Dome Mountain and 25 kilometres southwest of the Fraser River suspension bridge near the Gang Ranch (Figure 2-5-1). The airstrip half a kilometre southeast of the deposit is mostly overgrown by young spruce and jackpine trees.

GEOLOGICAL SETTING

The property is extensively covered by glacial till and alluvium. Bedrock exposures are mostly along the main road near the centre of the property and on the hillside to the southwest.

The hotspring deposit is a bright yellow siliceous encrustation, 10 to 30 metres thick, forming a terraced structure immediately overlying rhyolite obsidian (Plates 2-5-1 and 2-5-2). It covers an area measuring at least 150 metres across, as viewed on a switchback on the Porcupine Creek road. The distinctly layered aspect and bossed surface of the deposit suggest a thermal spring origin. Opalescent quartz, including a small amount of fire opal, fills crosscutting fissures and interstices between the yellowstone layers.

Similar deposits occur near the Aurun Mines Ltd. perlite operation in the Empire Valley, 6 kilometres to the east (Z.D. Hora, personal communication, 1986). They are correlated with obsidian on Porcupine Creek dated 26.1 ± 0.9 million years, which is similar to the age of the Black Dome basalt dated 24.0 ± 0.8 million years (Faulkner, 1986; Mathews, *et al.*, 1984).

DISCUSSION

Although the general geological setting of the Bubble Hotspring deposit is similar to the Blackdome mine a few kilometres to the west (that is, Eocene hornblende andesite and rhyolite country rocks), the obsidian immediately underlying the Bubble deposit is probably Miocene age and contemporaneous with the Black Dome basalt and the Porcupine Creek obsidian. Thermal and aqueous discharge from the cooling obsidian is the suspected origin of this yellowstone siliceous sinter deposit.

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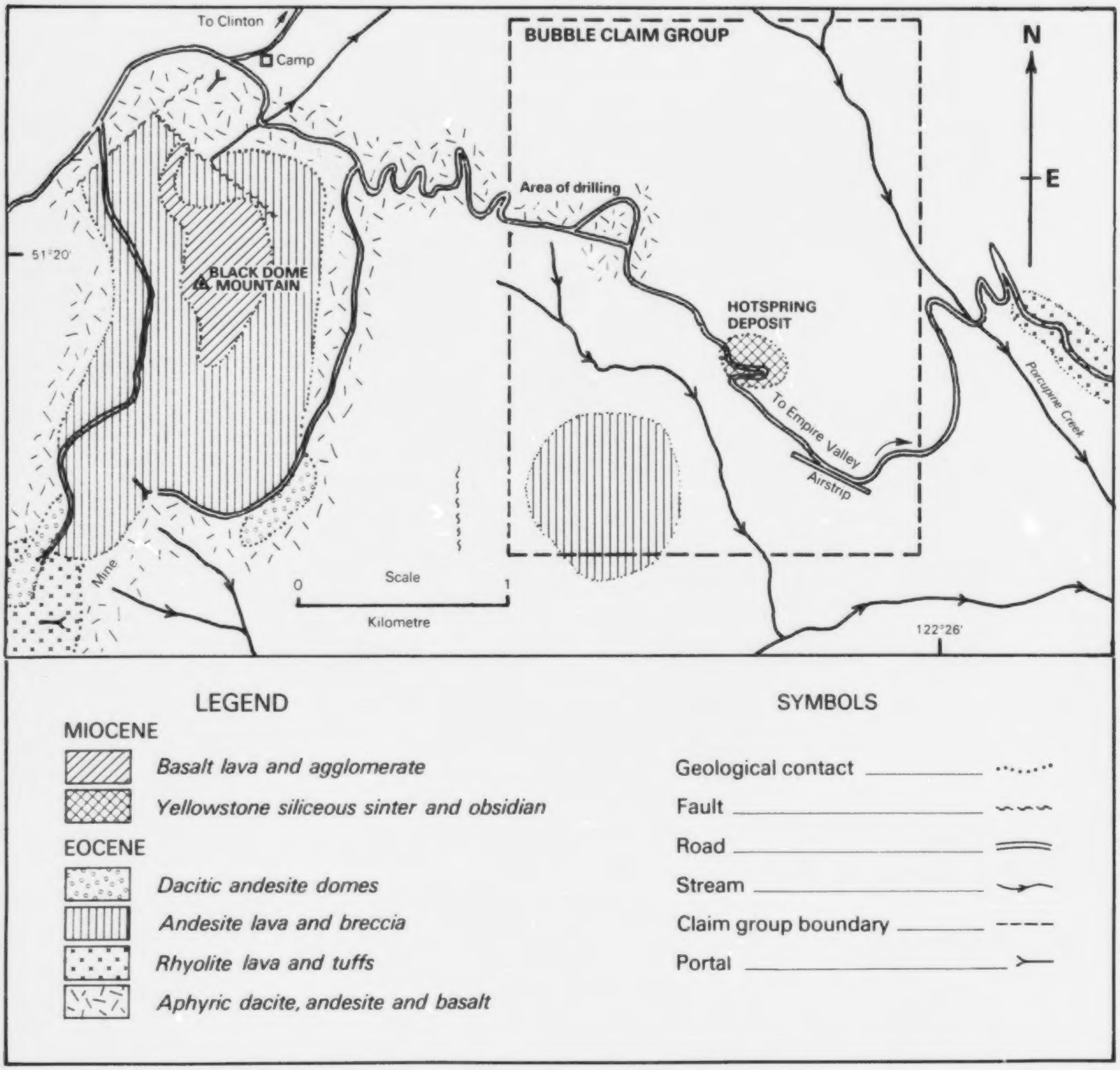
To Clinton
Camp
BUBBLE CLAIM GROUP
N
E
Area of drilling
51°20'
BLACK DOME MOUNTAIN
HOTSPRING DEPOSIT
To Empire Valley
Airstrip
Porcupine Creek
Mine
Scale
0
1
Kilometre
122°26'
LEGEND
MIOCENE
Basalt lava and agglomerate
Yellowstone siliceous sinter and obsidian
EOCENE
Dacitic andesite domes
Andesite lava and breccia
Rhyolite lava and tuffs
Aphyric dacite, andesite and basalt
SYMBOLS
Geological contact
Fault
Road
Stream
Claim group boundary
Portal

Figure 2-5-1. Geology in vicinity of the Bubble Hotspring deposit, Black Dome area.

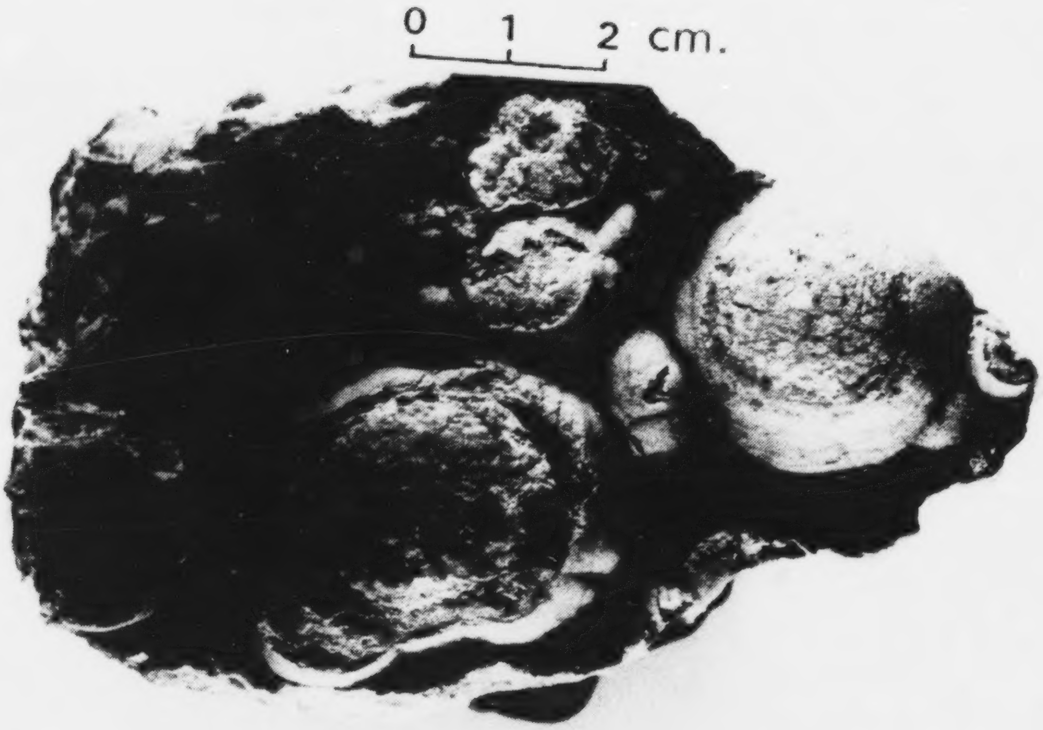

Plate 2-5-1. Bossed surface of yellowstone silica sinter.

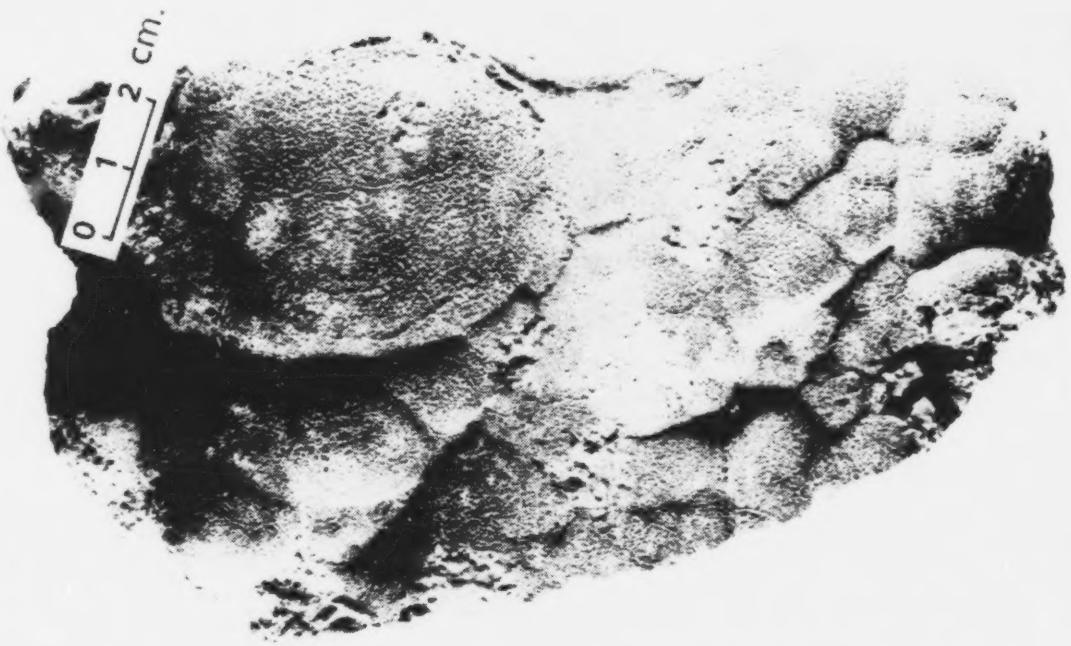

Plate 2-5-2. Yellowstone silica sinter. Bubble Hotspring deposit.

GEOLOGY OF THE HOPKINS PROPERTY INDIAN RIVER AREA SOUTHWESTERN BRITISH COLUMBIA

(92G/11)

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INTRODUCTION

The Hopkins property is centred near latitude 49°38′ north, longitude 123°0′30″ west at the headwaters of the Indian and Stawamus Rivers (Figure 2-6-1). Access from Squamish is by 10 kilometres of logging road that parallels the Stawamus River. The Britannia mine is 12 kilometres to the west and Vancouver is 40 kilometres south of the project area. Mapping by the senior author in the summer of 1986 was concentrated in areas of volcanogenic and vein copper, lead, zinc, and gold mineralization.

Shortly after the first discoveries were made in the Britannia mine area about 1910, the ABC group was staked at the headwaters of the Indian River (Lisle, 1981). Little work was recorded until 1969-1970 when New Jersey Zinc Exploration Co. (Canada) Ltd. explored in the area and Croydon Mines Ltd. completed a Turam geophysical survey and drilled some anomalies (Lisle, 1981). In 1976 Harold Hopkins staked 84 units in 11 claims after finding copper-lead-zinc mineralization (Clendenan and Pentland, 1979). A short tunnel and trenching exposed sub-ore-grade stringer veins. In 1978 and 1979 the property was optioned to Placer Development Ltd. and work included mapping, geochemical and magnetic surveys, trenching, and drilling of 11 holes totalling 1320 metres (Drummond and Howard, 1985) mainly on the War Eagle claims (northwest corner of Figure 2-6-1). Placer dropped its option in May 1980 (Drummond and Howard, 1985).

International Maggie Mines Ltd. has continued work since 1980. This has included drilling 52 holes totalling 4960 metres (Drummond and Howard, 1985) and driving a short adit and raise. Recent work has been concentrated on the Mar claim (southwest corner of Figure 2-6-1) along two parallel quartz-chlorite veins that carry sulphides with anomalous gold and silver values.

REGIONAL GEOLOGY

The project area lies on the eastern edge of the Britannia-Indian River roof pendant. This pendant consists of a submarine volcanic and sedimentary sequence of pyroclastics, flows, cherts, and argillites tentatively assigned to the Lower Cretaceous Gambier Group. Metamorphism is up to lower greenschist facies but most rock textures are intact. Bedding and foliation generally strike northwest and dip southwest. Cretaceous granodiorite intrusions of the Coast Plutonic Complex surround and intrude the pendant.

Close proximity to the Britannia mine makes exploration within the pendant attractive. A string of properties along the Indian River valley parallels the poorly understood Britannia shear zone.

LOCAL GEOLOGY

There are four main units shown in Figure 2-6-1. From oldest to youngest they are: (1) intermediate tuffs and flows, (2) lower felsic tuffs and flows, (3) sediments and (4) upper felsic tuffs and flows. These units have been intruded by Cretaceous granodiorite intrusions, which are responsible for the development of large zones of hornfels and secondary biotite enrichment. Biotite alteration is generally noted in mineralized areas also characterized by silicification and propylitization.

Intermediate tuffs and flows consist mainly of green andesitic to dacitic rocks outcropping in the centre of the valley. The pyroclastic rocks vary from fine-grained tuffs (hard to distinguish from flows in outcrop and hand specimen) to fragmental tuffs containing fragments up to 15 centimetres long. Flows are often feldspar porphyritic and sometimes have a chlorite amygdaloidal texture. Chlorite and epidote alteration of felsic tuffs is common and local strong development of secondary biotite makes the upper contact of this unit gradational and indistinct.

Lower felsic tuffs and flows occur stratigraphically above and on either side of the intermediate tuffs and flows. They are rhyolitic to dacitic. Flows are difficult to distinguish from cherty tuffs, except where they exhibit flow banding. The well-bedded tuffs are composed of fragments and crystals 1 to 2 millimetres long, and contain numerous layers of fragments that are several centimetres long. Some poorly mineralized horizons may correlate with those intersected by drilling at portal one (Figure 2-6-1). The top of this unit interfingers with the overlying sediments.

Sediments are composed of chert and shale exposed west of the valley. Several depositional cycles, interbedded with tuffaceous units, are represented. Most sediments are very fine grained, but a few siltstone, sandstone and coarser fragmental tuff layers are present. Chert layers are commonly 1 to 2 centimetres thick, but they also occur as massive beds up to 2 metres in thickness. The shales are usually pyritic and siliceous. Bedding is well developed and often shows tops to the southwest.

Upper felsic tuffs and flows form a thick section. Fragments are up to 10 centimetres long. These rocks are similar to the lower felsic unit, except that tuffs are more abundant and fragments coarser. At portal two the tuffs hosting the veins are hornfelsed to a massive, brown, biotite-rich rock characterized by pale-coloured, resistant ovoids of cordierite and quartz 3 to 10 millimetres in diameter, that form up to 30 per cent of the rock. The original textures are destroyed within this hornfelsed zone. The spatial relationship of chalcopyrite-pyrite mineralization and hornfelsed zones suggests that vein development was controlled by the fracturing characteristics of the hornfels.

Intrusions include plutons, dykes and sills of granodiorite, andesite and basalt. The granodiorite is part of the Cretaceous Coast Plutonic Complex that surrounds the roof pendant. Numerous andesite and basalt dykes are present. An extensive sill of hornblende porphyry basalt contains up to 20 per cent hornblende phenocrysts in a groundmass of feldspar microlites. Its irregular outcrop pattern is caused by the variable topography. Several large andesite dykes occur near portal two.

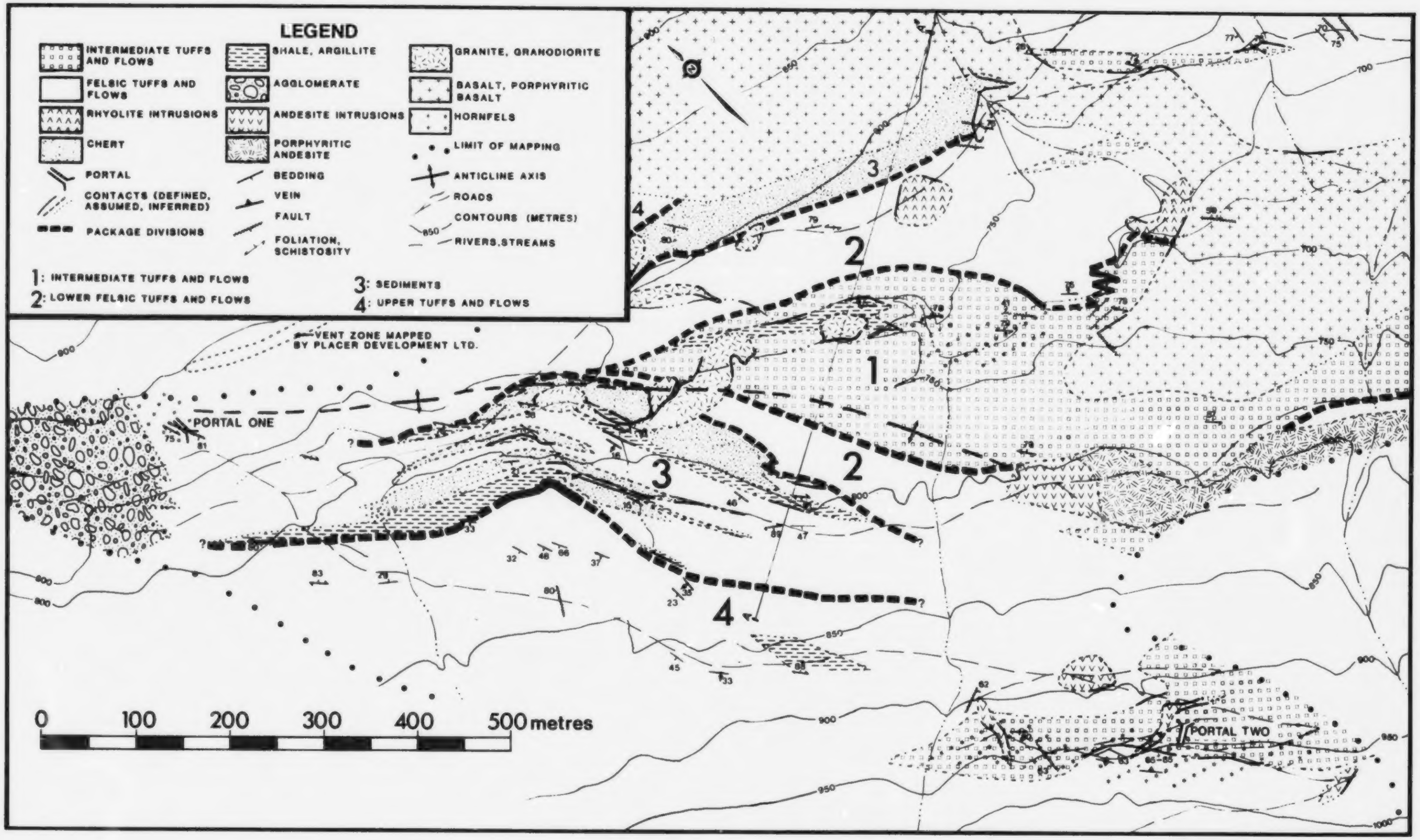
LEGEND
INTERMEDIATE TUFFS AND FLOWS
FELSIC TUFFS AND FLOWS
RHYOLITE INTRUSIONS
CHERT
PORTAL
CONTACTS (DEFINED, ASSUMED, INFERRED)
PACKAGE DIVISIONS
SHALE, ARGILLITE
AGGLOMERATE
ANDESITE INTRUSIONS
PORPHYRITIC ANDESITE
BEDDING
VEIN
FAULT
FOLIATION, SCHISTOSITY
GRANITE, GRANODIORITE
BASALT, PORPHYRITIC BASALT
HORNFELS
LIMIT OF MAPPING
ANTICLINE AXIS
ROADS
CONTOURS (METRES)
RIVERS, STREAMS
1: INTERMEDIATE TUFFS AND FLOWS
2: LOWER FELSIC TUFFS AND FLOWS
3: SEDIMENTS
4: UPPER TUFFS AND FLOWS
VENT ZONE MAPPED BY PLACER DEVELOPMENT LTD.
PORTAL ONE
PORTAL TWO
1
2
2
3
3
4
4
0
100
200
300
400
500 metres
700
750
800
850
900
950
1000

Figure 2-6-1. Geology map of the Hopkins property at the headwaters of the Indian River.

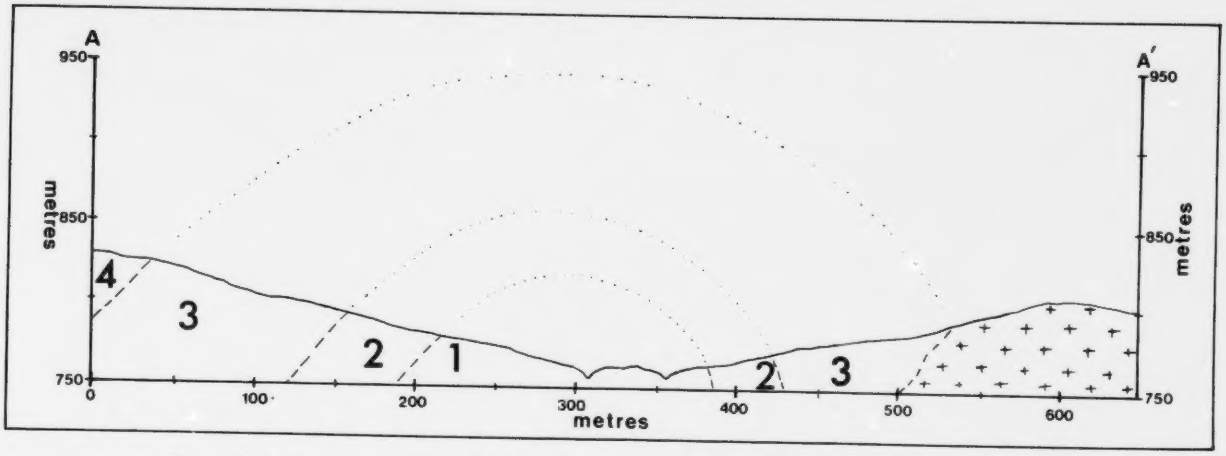

Figure 2-6-2. Cross-section A-A' of the Hopkins property. The section line is shown in Figure 2-6-1.

STRUCTURE

West of the Indian River bedding strikes northwest, dips southwest and shows numerous good tops facing southwest. Near portal one (Figure 2-6-1) bedding is flat to gently southwest-dipping. East of the Indian River bedding strikes northwest and dips steeply northeast. The dip reversal is interpreted as an anticline (Figure 2-6-2) that is tilted to the northeast. A pervasive axial plane cleavage strikes northwest and dips steeply to the southwest. Cleavage and bedding attitudes in the west half of the valley indicate the axis of the anticline lies to the northeast and has a shallow northwesterly plunge. Drill-hole data confirms this interpretation (Drummond and Howard, 1985).

A second cleavage striking north and dipping moderately to the west is axial planar to minor folds with steep northwesterly plunging axes.

Faults and shear zones generally strike north to northwest but northeast-trending structures have been mapped near portal two.

MINERALIZATION

Work on the property has been concentrated in the mineralized areas at portal one and portal two (Figure 2-6-1).

An adit has been driven from portal one along a zone of shearing approximately 50 centimetres wide and containing remobilized or stringer mineralization with average grades of 0.50 per cent copper, 0.35 per cent zinc, and 0.20 per cent lead (Clendenan and Pentland, 1979). Mineralization is interpreted to be volcanogenic; similarities to the Kuroko model include explosive volcanism, alteration, and stringer and stratiform ore that is dominantly pyrite with chalcopyrite, sphalerite and galena.

Mineralization at portal two consists of two quartz-chlorite veins containing up to 15 per cent sulphides including pyrite, chalcopyrite, sphalerite and traces of galena. Both veins carry significant values in gold and silver. The Main vein and East vein are parallel, striking northwest and dipping steeply to the northeast. They consist of a core of higher grade mineralization about 1 metre wide with lower grade material at the margins. The host rock is mainly massive, brown, biotite-rich pyritic hornfels.

The Main vein is 30 to 107 centimetres wide, over 70 metres long and averages 68.5 grams per tonnes (1.91 ounces per ton) gold over a 31-centimetre width (Drummond and Howard, 1985). The East vein, 9 metres to the northeast, is 30 to 198 centimetres wide and known to be at least 20 metres long (Drummond and Howard, 1985).

Two other areas of chalcopyrite-pyrite mineralization are shown in Figure 2-6-1. One is at the top and sides of a rhyolite dome 0.9 kilometre southeast of portal one. The rhyolite is pale green and contains quartz "eyes" and plagioclase crystals in a fine-grained groundmass. The second is in a hornfelsed zone exposed in the Indian River near the centre of the project area.

CONCLUSIONS

The Britannia-Indian River pendant is a highly productive and prospective volcano-sedimentary sequence containing the Britannia orebodies and a number of other mineralized occurrences. Bedded tuffs, flows, and sediments have been deformed into an anticline with a fold axis that plunges gently northwest. Mineralization on the Hopkins property includes: (1) a volcanogenic system with low-grade stratiform layers and some crosscutting stringer zones near portal one and (2) higher grade gold mineralization in quartz-chlorite veins cutting hornfels at portal two, which are the focus of current interest.

ACKNOWLEDGMENTS

The authors thank the British Columbia Ministry of Energy, Mines and Petroleum Resources for the grant supporting this project. Harold Hopkins kindly gave permission to work on the Maggie property and to use the camp. Corporation Falconbridge Copper provided some field support. Harold Gibson of Falconbridge Copper gave helpful field guidance. Gary Sutton was an able assistant on the project.

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GEOLOGY OF THE BEND ZINC-LEAD-SILVER MASSIVE SULPHIDE PROSPECT SOUTHEASTERN BRITISH COLUMBIA*

(83D/1)

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INTRODUCTION

The Bend massive sulphide body is conformably hosted by metasedimentary rocks of the Park Ranges in the Rocky Mountains (Figure 2-7-1). The deposit outcrops in the Cummins River canyon on McNaughton Lake and in a roadcut 3.5 kilometres to the northwest. Mineralization in the Cummins River canyon was first discovered during construction of the Big Bend Highway and claims were staked by highway workmen in 1949 (Oliver, 1985). These claims lapsed and in 1966 The Consolidated Mining and Smelting Company of Canada, Limited (Cominco Ltd.) staked 45 claims as the Bend group. Cominco retains 12 of the original claims covering the canyon zone.

The Bend showing is exposed on the north and south walls of the Cummins River canyon, but flooding to the 750-metre elevation by the Mica hydroelectric dam has partly submerged the showings. Detailed mapping of a 100-metre section (Figures 2-7-2 and 2-7-3) centred on the prospect was completed by the senior author over a four-day period in June 1985 (Reddy, 1986).

REGIONAL GEOLOGY

The Cummins River area is dominantly underlain by Proterozoic miogeosynclinal rocks (Höy *et al.*, 1984) that form a thick, conformable stratigraphic succession on the western limb of the Porcupine Creek anticlinorium (Figure 2-7-1); the units strike northwest and dip southwest. These sedimentary rocks have been metamorphosed to amphibolite of garnet-staurolite-kyanite grade. The region exhibits well-defined metamorphic isograds that trend northwest with grade increasing toward the southwest (Craw, 1978).

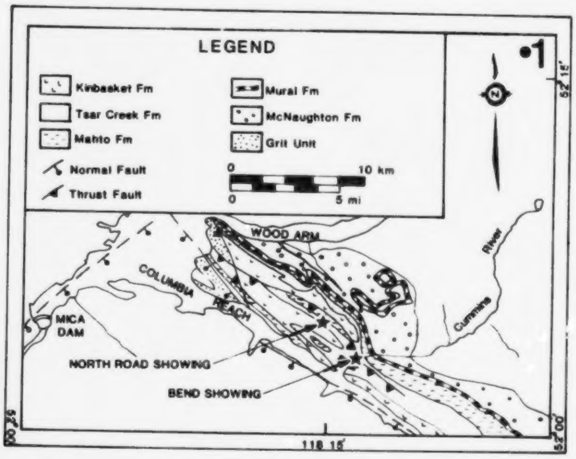

Figure 2-7-1. Regional geology of the Bend property, Cummins River canyon area (after Simony *et al.*, 1980). Geology is shown only for the area surrounding the North Road and Bend showings. The northwest-trending axis of the Porcupine Creek anticlinorium passes approximately through point 1.

The Late Cambrian Gog and Middle Cambrian Chancellor Groups overlie the Hadrynian Miette Group in the property area. Two of three formations in the Chancellor Group, Kinbasket and Tsar Creek, outcrop in the Cummins River canyon. The Tsar Creek Formation hosts the sulphide showing; the stratigraphic section from hangingwall to footwall described here is entirely within this formation.

Many of the layers in the Tsar Creek Formation are tightly folded with axial planes striking northwest and dipping steeply southwest (Dodson, 1971). The Early Cambrian age is based on fossils in equivalent unmetamorphosed strata to the south of the map area, near Sullivan River (Fyles, 1960). There are no volcanic rocks in the immediate area of Cummins River.

LOCAL GEOLOGY

The 100-metre exposure examined along shoreline in the Cummins River canyon is a conformable sedimentary sequence within the Tsar Creek Formation (Figure 2-7-3). Foliation and bedding attitudes are similar and strike northwest and dip southwest, but foliation dips more steeply than bedding. This relationship, structural vergences, and elemental and compositional zoning in the sulphide deposit, indicate that the units are upright. Simony *et al.* (1980) mapped an overturned anticline-syncline pair in the canyon; the section studied is apparently on the east limb of the syncline.

Host rocks to the sulphide deposit are metamorphosed clastics, chert, and argillites. The footwall, the sulphide zone, and the hangingwall are described below and in Figure 2-7-2.

FOOTWALL

The footwall of the sulphide lens consists of four rock types. From stratigraphically lowest to highest they are quartzite, siliceous dolomite, garnet biotite schist and garnet mica schist. The quartzite is bedded and composed of mostly recrystallized and strained quartz grains (85 per cent) with associated micas, garnet, tourmaline, and staurolite. It is at least 35 metres thick and extends beyond the section studied. The dolomite (80 per cent carbonate) is siliceous with up to 20 per cent quartz and minor micas. The garnet biotite schist, above the dolomite, is a 1-metre-thick layer containing porphyroblastic garnet and biotite crystals within a micaceous groundmass. The garnet mica schist, separated from the garnet biotite schist by a 3-metre-thick quartzite layer, is 11 metres thick and consists of subhedral porphyroblastic almandine garnets up to 1

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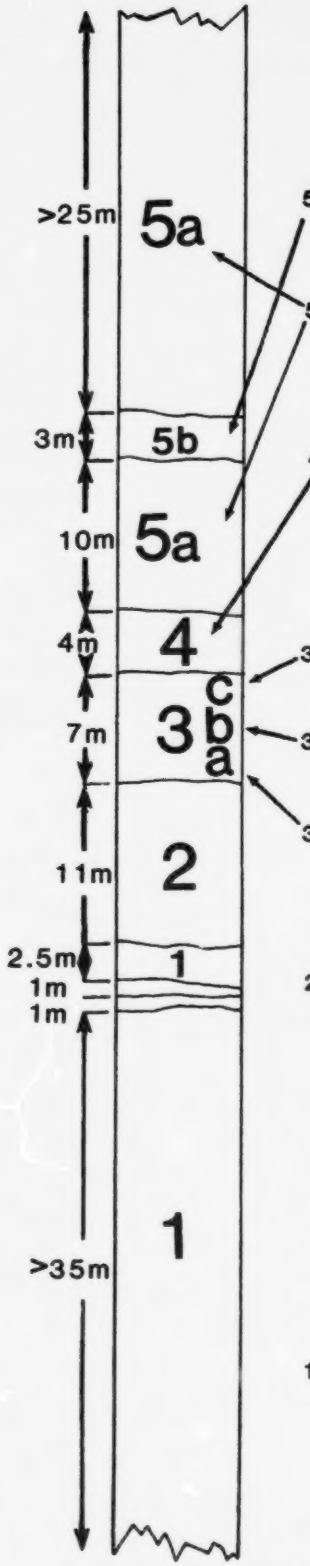
* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.



HANGINGWALL

5b CRYSTALLINE IMPURE LIMESTONE: beds up to 3m thick of carbonate (70-90%) with ≤30% quartz and minor aluminous minerals.

5a GARNETIFEROUS CARBONATE: schistose to gneissose carbonate (45-70%) with ≤25% porphyroblastic garnets ≤3.5cm across, 20-40% quartz, ≤18% micas, and ≤10% plagioclase.

4 IMPURE QUARTZITE: well layered with 80-50% quartz (decreases at upper contact with increase in pelite).

SULPHIDE ZONE

3c MANGANIFEROUS DOLOMITE with lenses of pyrite, sphalerite, and galena.

3b SOLID,SILICEOUS SULPHIDE (dominantly quartz , pyrite, and pyrrhotite).

3a MASSIVE SULPHIDE (mainly pyrite, pyrrhotite, sphalerite and galena)

FOOTWALL

2 GARNET MICA SCHIST: 45-80% muscovite, 30% quartz, ≤ 20% biotite, and ≤5% porphyroblastic garnets up to 1cm across.

GARNET BIOTITE SCHIST: ≤ 80% muscovite and porphyroblastic biotite, 10% porphyroblastic garnet, and 10% quartz.

SILICEOUS DOLOMITE LENS: 80% carbonate, 18% quartz and 2% micas.

1 QUARTZITE: 80% quartz, 15% mica, 5% opaques.

Figure 2-7-2. Detailed stratigraphic column of the 100-metre section studied in the Cummins River canyon. Unit numbers correspond to those in Figures 2-7-2 and 2-7-3.

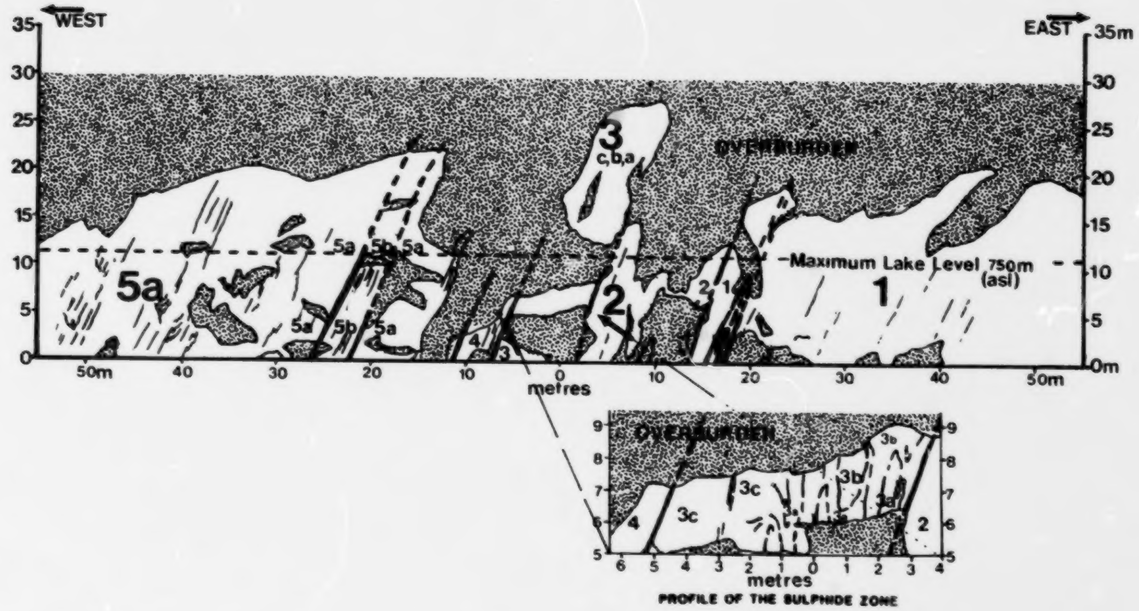


Figure 2-7-3. Profile of the Bend occurrence, Cummins River canyon. Zero on the vertical scale is the level of McNaughton Lake in June 1985; 11 metres is the maximum level of the lake. Unit numbers correspond to Figure 2-7-2.

centimetre in diameter associated with minor staurolite, kyanite and zoisite. Micas exhibiting strain-slip cleavage constitute 45 to 80 per cent of this unit which conformably underlies the sulphide zone.

SULPHIDE ZONE

The sulphide zone is a conformable layer within the metamorphosed argillite and quartzite host (Plate 2-7-1A). Intense deformation has preferentially folded the ductile sulphide layers (Plates 2-7-1B and 2-7-1C); this has hampered zoning studies. The mineralized zone can be divided into three units: massive sulphide, siliceous sulphide and mineralized manganiferous dolomite. The thickness of the combined sulphide layers is 5 metres at the detailed section, thickening down dip to 10 metres (Leask, 1981). Down dip the zone is submerged under the Mica Dam reservoir.

The massive sulphide layer lies immediately above the garnet mica schist of the footwall. Siliceous sulphide layers alternate with and are interfolded in the crumbly sulphides and overlying manganiferous dolomite. The massive sulphide consists mainly of pyrite, but grades into a siliceous sulphide layer that is dominantly quartz, garnet and carbonate. "Ore" minerals, in order of abundance are: pyrite, pyrrhotite, sphalerite, galena and magnetite, with minor arsenopyrite and chalcopyrite. Pyrite generally occurs as subhedral porphyroblasts up to 3 millimetres across or as annealed masses showing foam texture. Galena and chalcopyrite have been mobilized and are often found in cracks and pressure shadows of pyrite and spessartine (*see* following) garnet grains. Minor amounts of barite are reported, but none was observed in the detailed section and barium analyses do not show high values. The grade of the Bend sulphide occurrence is estimated at 3 per cent zinc, 1 per cent lead, and less than 16 grams silver per tonne.

Manganese dolomite is "chocolate weathering" due to manganese oxide coatings. The dolomite is cream to brown in colour and contains mica-rich layers. Lenses of massive pyrite, sphalerite, and galena occur within it.

The North Road Zone of sulphides (Figure 2-7-1) outcrops about 3.5 kilometres northwest of the Bend Canyon Zone. The two zones may be at the same stratigraphic level (Leask, 1981). Certainly the mineral assemblage and grades are similar, but the sulphides are mostly hosted by dolomite in the North Road occurrences. If the sulphide layer is continuous between the two outcrops, a strike length of at least 3.5 kilometres is indicated and significant tonnage potential exists.

HANGINGWALL

The hangingwall is a conformable sequence of quartzite, garnetiferous carbonate, and impure crystalline limestone. The manganiferous dolomite at the top of the sulphide zone has a sharp contact with a 4-metre-thick quartzite bed (Plate 2-7-1D). The quartzite decreases in quartz content and becomes a micaceous schist at the top of the unit. A garnetiferous carbonate overlies the quartzite and represents the remainder of the section studied. Numerous impure crystalline limestone lenses and layers, mostly less than 1 metre thick, occur within this unit (one layer is 3 metres thick). The garnetiferous carbonate consists of modal percentages of carbonate (45 to 70 per cent), quartz (20 to 40 per cent), garnets (up to 25 per cent), and plagioclase (up to 10 per cent). The euhedral, porphyroblastic almandine (*see* following) garnets are up to 3.5 centimetres in diameter.

GARNET COMPOSITION

Garnets were examined with a scanning electron microscope to determine changes in composition with respect to position in the stratigraphic section. The garnets sampled were from a 12-metre section extending from the footwall through the sulphide zone and into the hangingwall. The lowest garnet sample from the footwall (Figure 2-7-4A) is almandine [$Fe_3Al_2(SiO_4)_3$]. Within the sulphide zone (Figures 2-7-4B and 2-7-4C) and in the hangingwall (Figure 2-7-4D) the garnets are almost entirely spessartine [$Mn_3Al_2(SiO_4)_3$].

Investigations of the change in compositions of almandine garnets with respect to temperature indicate that weight per cent MnO

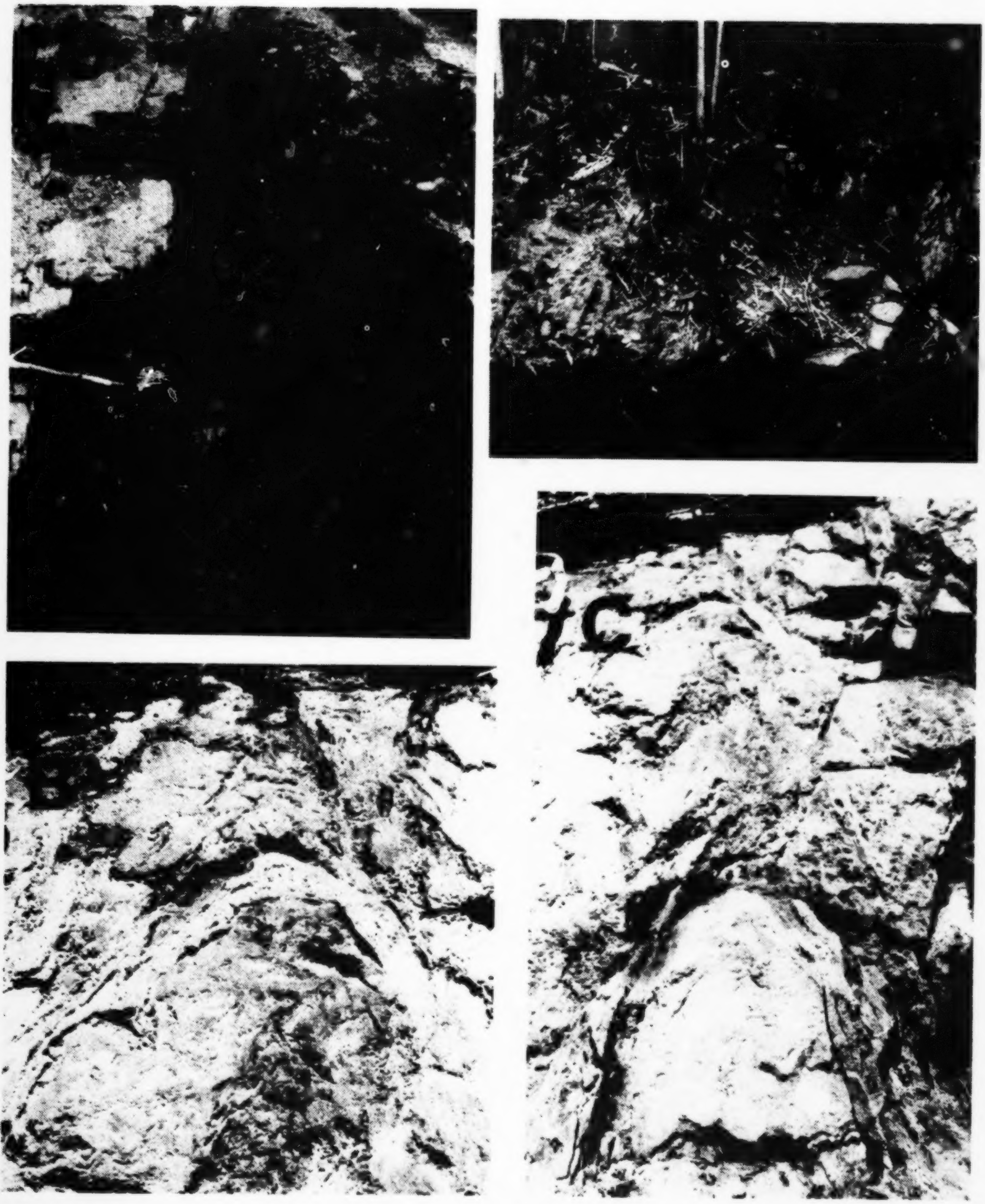


Plate 2-7-1A, B, C, D. Photographs of the Bend massive sulphide showing looking north. A = general view of showing as exposed in the Cummins River canyon; B and C = fold forms in siliceous and sulphide-rich layers; D = quartzite hangingwall over manganiferous dolomite.

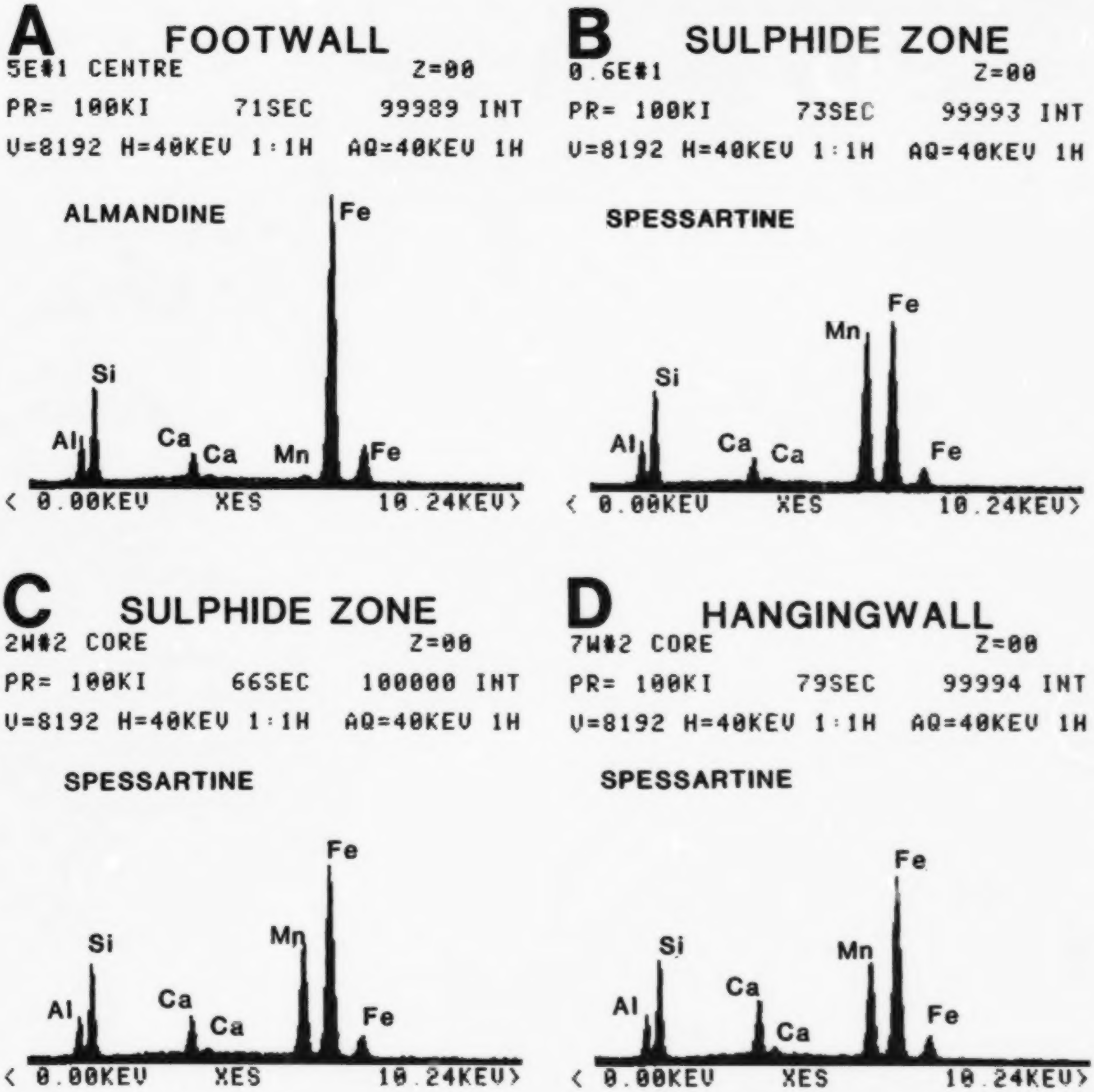


Figure 2-7-4A, B, C, D. Scanning electron microscope analyses of garnets defining the elemental constituents and relative amounts of elements present. Figure 2-7-4A is an almandine garnet [Fe_3Al_2 $(SiO_4)_3$] from the footwall. Figures 2-7-4B and 2-7-4C (sulphide zone), and 2-7-4D (hangingwall) are spessartine garnets [Mn_3Al_2 $(SiO_4)_3$].

and FeO decrease and increase respectively with an increase in temperature (Miyashiro, 1973). Although metamorphic grades, and therefore temperatures, in the Cummins River area increase regionally from east to west, the limited distance between samples suggests that the changes in MnO and FeO content of garnets observed in the Canyon Zone are related to the original bulk composition of the host rocks. Specifically, the manganese-rich garnets probably reflect a manganiferous exhalite horizon associated with and immediately above the sulphide layer. This capping manganiferous exhalite is coincident with other younging directions.

LEAD ISOTOPE DATA

Lead isotope analyses from the North Road Zone, probably stratigraphically equivalent to the Canyon Zone, are: $^{206}Pb/^{204}Pb = 18.204$, $^{207}Pb/^{204}Pb = 15.612$, $^{208}Pb/^{204}Pb = 37.996$. This gives a Hadrynian-Cambrian age as modelled on the shale curve (Godwin and Sinclair, 1982).

DISCUSSIONS AND CONCLUSIONS

The Bend occurrence is a stratiform, synsedimentary, exhalative massive sulphide body that was formed within the unstable cratonic margin of North America in the Early Paleozoic (Hadrynian-Cambrian). Original host lithologies include shale, chert, pelitic chert and manganiferous carbonate units consistent with deposition in a "starved basin" (Eckstrand, 1984).

The metalliferous sediments were probably deposited from dense, metal-rich brines derived from compaction of the sedimentary pile. Such brines exhaled onto the sea floor can be denser than sea water, in which case the solutions would pond in major depressions (Gustafson and Williams, 1981). Other chemical sediments, such as the iron and manganese-rich metamorphosed chert above the Bend sulphides, are commonly associated with the end of sulphide deposition.

Several structural events have resulted in folding of the host units and the sulphides. Metamorphism has reconcentrated galena, chalcopyrite and pyrrhotite into low pressure areas. Regionally, the deposit is on the east limb of a major anticlinorium. Within the Cummins River canyon the deposit is right-side-up on the east limb of a syncline. The stratigraphic younging direction from east to west is supported by structural criteria and by changes in the composition of garnets.

ACKNOWLEDGMENTS

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CAPOOSE PRECIOUS AND BASE METAL PROSPECT
CENTRAL BRITISH COLUMBIA
(93F/6E)

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INTRODUCTION

The Capoose precious and base metal prospect in central British Columbia (Figure 2-8-1) is centred at latitude 53°16′ north and longitude 125°9′ west, 2 kilometres north of Fawnie Nose and approximately 110 kilometres southeast of Burns Lake. Access is by helicopter or by four-wheel-drive road off kilometre 142 on the main Kluskus-Ootsa logging road running southwest from Vanderhoof.

The property covers a geochemical anomaly discovered prior to 1969 by Rio Tinto Canadian Exploration Ltd. Riocanex worked on the property between 1969 and 1971. Work from 1976 to 1985 by Granges Exploration Ltd. in joint venture with Bethlehem Copper Corp. and later with Cominco Ltd. has included diamond drilling totalling 13 285 metres in 85 holes.

This report is based on a two-week mapping project in the main area of mineralization, undertaken in late August and early September 1986. The project is part of an M.Sc. thesis in progress by the senior author.

REGIONAL GEOLOGY

The Fawnie Range, in the vicinity of the Capoose prospect, is a northwest-trending sequence of synclinally folded Lower and Middle Jurassic Hazelton Group rocks intruded by the Cretaceous or Tertiary granitic Capoose batholith. The area studied lies in Middle Jurassic Hazelton Group rocks in fault contact with Lower Jurassic rocks to the north and south (Tipper *et al.*, 1974). The Lower Jurassic Hazelton Group consists of andesitic to rhyolitic tuff, breccia, flows and sedimentary rocks; the Middle Jurassic Hazelton Group includes basalt, andesite, tuff, breccia, greywacke, mudstone and conglomerate (Tipper *et al.*, 1974).

Rocks of the Nechako Plateau are characterized by low-grade regional metamorphism. Contact metamorphism around plutons is pronounced (Tipper, 1963). Although the deformation of the rocks is not generally intense, Tipper (1963) suggests that commonly featureless volcanic rocks may mask complex fold patterns.

The Hazelton Group is characterized by open folding with dips up to 45 degrees. In the vicinity of the Capoose prospect, rocks are synclinally folded; the axis of the syncline trends northwest and passes 5 kilometres northwest of the centre of the study area.

LOCAL GEOLOGY

STRATIGRAPHY

Detailed mapping at a scale of 1:2500, and core logging of a representative cross-section on the Capoose property, has defined 10 map units in the main area of mineralization (Figure 2-8-1). The map units are divided into four assemblages: a lower mafic volcanic package (Unit 1), a central volcaniclastic package (Units 2 to 5), an upper felsic volcanic package (Units 6 to 8), and an intrusive package (Units 9 and 10). Principal lithologic units are shown in Figure 2-8-1 and described in detail following.

Lower mafic volcanic package, Unit 1, is typically massive and locally scoriaceous basaltic andesite. Some interflow conglomerate, with felsic, altered felsic and dark basalt fragments, is included in the unit which crops out in the northeast part of the map area. Locally, stretched amygdules (2 by 1 centimetre) are infilled mainly by calcite and quartz and have a northeasterly elongation. The unit is propylitized as evidenced by the abundant replacement of mafics by chlorite, the calcite-quartz amydules and calcite veinlets (1 to 2 millimetres wide) that cut the unit.

Central volcaniclastic package, Units 2 to 5, lies conformably above the basaltic andesites and consists of felsic lapilli tuffs interbedded with dacite flows, argillite, and lithic wacke. Felsic lapilli tuff, Unit 2, has a pale grey aphanitic groundmass which supports varying amounts of clasts 1 to 10 millimetres across. Devitrification has resulted in aphanitic and poorly formed spherulitic fabrics. A dacite flow, Unit 3, in the northeastern part of the study area, shows conformable contacts with bedding in adjacent lithic wacke and felsic lapilli tuff. This unit looks like andesite in hand specimen, but in thin section is seen to contain 1 per cent anhedral embayed quartz crystals. Thinly bedded argillite and ash tuff, Unit 4, outcrops in the central portion of the area. Tuff beds range from 1 to 5 centimetres thick and are interbedded with argillite every 10 centimetres within the sequence. Indicators of tops, such as graded bedding, load casts, rip-up clasts and pull-apart structures, show the section to be right-side-up. The lithic wacke, Unit 5, is poorly sorted with approximately 60 per cent matrix and rock fragments, 20 per cent feldspar grains and 20 per cent quartz grains. Rocks of this composition are chiefly volcanic sandstones formed by direct reworking of pyroclastic material. Discontinuous beds of sandy limestone pinch and swell in outcrop. Locally this unit contains abundant fossils, some of which have been identified by H. Frebold (Tipper, 1963: No. 4 GSC Locality 20116-2, 4 kilometres from north end of Fawnie Nose) as *Belemnites*, species indeterminate, and *Rhynchonella*, species indeterminate. Unfortunately, only a broad Jurassic to Cretaceous age can be inferred for these fossils.

Upper felsic volcanic package, Units 6 to 8, conformably overlies the central volcaniclastic package. It is characterized by a sequence of flow-banded, spherulitic, garnetiferous quartz rhyolite and rhyolite flows with interbedded recessive-weathering, fossiliferous lithic wackes. A quartz garnet rhyolite flow, Unit 6, is characterized by 7 per cent embayed quartz phenocrysts (1 to 2 millimetres across) and 3 per cent anhedral garnet crystals in a devitrified aphanitic felt-textured groundmass. The garnets are occasionally zoned, exhibit weak birefringence, are intergrown by muscovite and are rimmed by muscovite and quartz. Garnet rhyolite, Unit 7, is commonly flow banded and contains spherulite-like balls (1 to 3 centimetres in diameter). Lithophysae, seen in thin section, are often lined with quartz. This unit has 5 per cent anhedral garnets interwoven with quartz aggregates and surrounded by a felt-textured aphanitic groundmass. Rare tourmaline, associated with garnet, has been noted in thin section. Rhyolite, Unit 8, is predominantly aphyric. However 1 to 2 per cent anhedral garnet crystals are associated with rare spherulite-like balls, 5 to 30 centimetres in

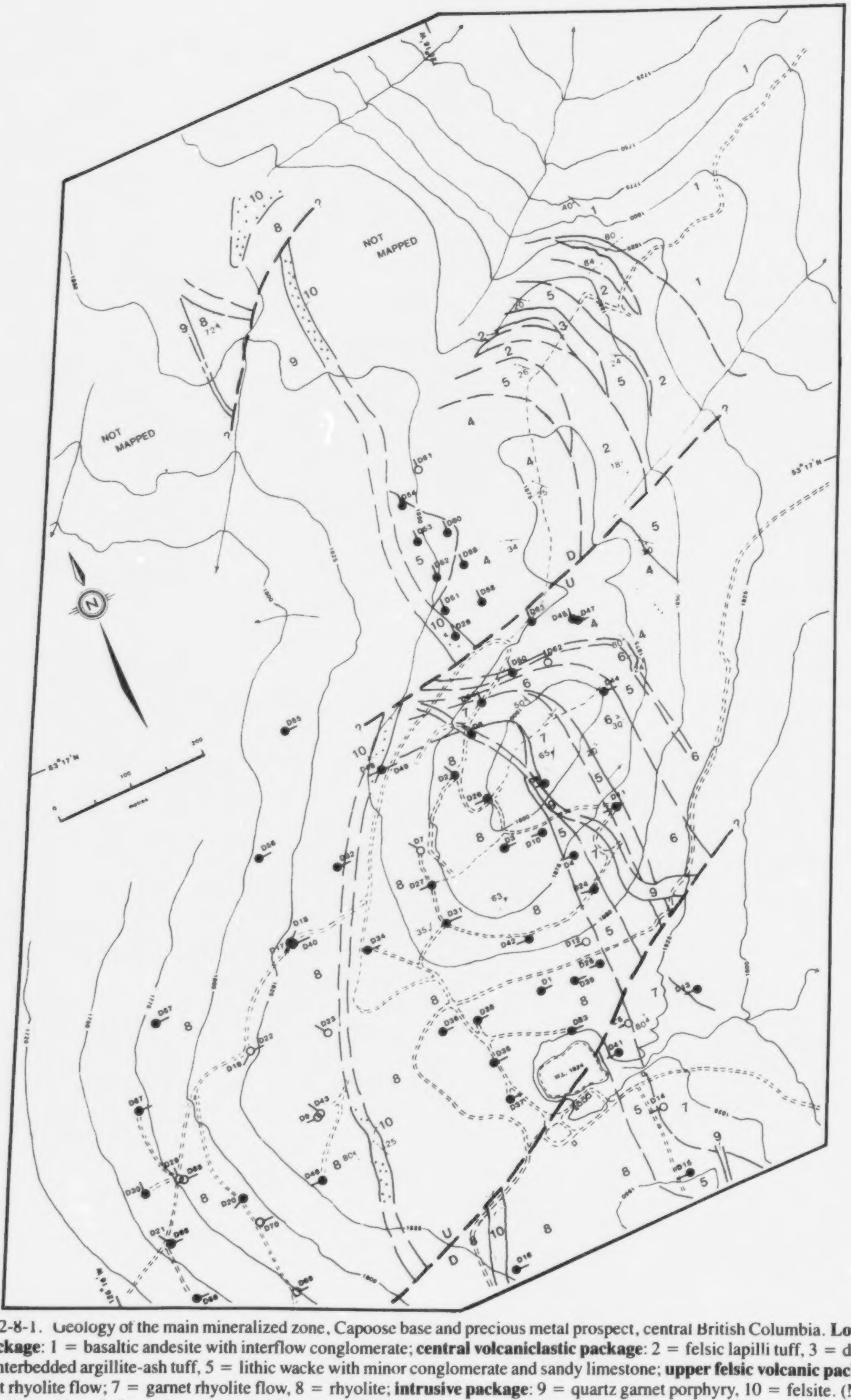

Figure 2-8-1. Geology of the main mineralized zone, Capoose base and precious metal prospect, central British Columbia. **Lower mafic volcanic package**: 1 = basaltic andesite with interflow conglomerate; **central volcaniclastic package**: 2 = felsic lapilli tuff, 3 = dacite flow, 4 = thinly interbedded argillite-ash tuff, 5 = lithic wacke with minor conglomerate and sandy limestone; **upper felsic volcanic package**: 6 = quartz garnet rhyolite flow; 7 = garnet rhyolite flow, 8 = rhyolite; **intrusive package**: 9 = quartz garnet porphyry, 10 = felsite. (Note: solid drill holes indicate where information was available; open drill holes indicate no available information).

diameter close to autobrecciated zones in the rhyolite. Flow banding is common in Unit 8. Most of the unit is sericitized and disseminated pyrite is common.

Conformity between lower, central and upper packages is evident from field relationships. Although flow banding within the rhyolite units is markedly variable, it generally parallels the argillite-rhyolite contact. Measurements of columnar jointing in the rhyolite flows (Figure 2-8-1) substantiate a conformable relationship between the upper and central packages, as does continuity of the interbedded lithic wacke unit between them. The interbedded volcanic-sedimentary succession (Units 1 to 8) represents a marine basin with deposits of fine muds and sands interlayered with flows, tuffs, and breccias which covered most of the Nechako Plateau in Early Jurassic time (Tipper, 1963).

Intrusive package, Units 9 and 10, consists of two crosscutting units: a quartz garnet porphyritic dyke (Unit 9) and a felsite dyke (Unit 10). Unit 9 dips shallowly to the southwest and is characterized by 1 per cent anhedral garnet and 5 per cent corroded quartz crystals in a matrix of equigranular quartz and feldspar. The rims of quartz and muscovite surrounding garnets are less distinct than in the older rhyolite units. Unit 10 crosscuts stratigraphy and appears to dip steeply to the east (Figure 2-8-1). At surface, the cream-coloured unit appears as a platy rubble subcrop (denoted by crosses in Figure 2-8-1). In thin section devitrification is represented by an aphanitic groundmass and microspherulites. Much of the unit is kaolinized and sericitized.

STRUCTURE

Detailed mapping of the northeastern limb of the syncline on Fawnie Range shows units dipping 20 to 40 degrees to the southwest. Measurement of cleavage-bedding intersections in the argillite-tuff and steeply dipping A-C joint surfaces in felsic tuffs and dacites indicates that the synclinal fold axis plunges gently (10 degrees) toward the southeast.

East-west faults are the predominant regional structures in the area. Fault traces are marked by linear depressions on Fawnie Range (Schroeter, 1981). Detailed mapping has defined two northeast-trending dip-slip faults which cut all map units (Figure 2-8-1). The two faults appear to mark the boundaries of a minor horst.

METAMORPHISM

Hornfelsic argillite tuff, recrystallized limestone, and possibly porphyroblastic garnet in rhyolite suggest contact metamorphism probably related to the Capoose batholith lying to the west of the property. Potassium-argon dating of this pluton is in progress.

ALTERATION

Much of the felsic volcanic package has been pervasively kaolinized and sericitized. Abundant quartz veining was not observed. The intensity of phyllic alteration has been mapped qualitatively and shown in Figure 2-8-2. Zones of high or intense phyllic alteration generally correspond with mineralized areas outlined by diamond drilling. The limit of hornfelsic alteration in argillite and lithic wacke is estimated in Figure 2-8-2. The alteration is being dated.

Rims of quartz and sericite are observed around garnets in the rhyolite units. Primary, porphyroblastic or xenocrystic origin for these garnets has yet to be established.

Epidote and chlorite are common alteration products in the andesitic rocks. These rocks are marginal to the deposit area and this may represent regional greenschist metamorphism rather than peripheral propylitization.

MINERALIZATION

Church and Diakow (1982) delineated a broad silver lithogeochemical anomaly near Capoose Lake which coincides with locally high values for lead discovered in 1970 by Rio Tinto Canadian Exploration Ltd. Three zones of precious and base metal mineralization have been identified on the property (Schroeter, 1981); two are hosted by garnetiferous rhyolite, the third by hornfelsed argillite.

Only core from zones 1 and 2, within the garnetiferous rhyolite, was examined in 1986. These zones are typified by galena, pyrite, pyrrhotite, chalcopyrite, arsenopyrite and sphalerite occurring mainly as disseminations and sometimes as veinlets. Some replacement of garnets by pyrite was also seen. Tetrahedrite, pyrargyrite, electrum, native gold and cubanite have been observed by Granges Exploration Ltd. Silver and minor gold (ratio 280:1) are associated with the galena and sphalerite (Schroeter, 1981). Sulphides commonly occur adjacent to and intergrown with garnet. The best intersections in drill core are: 126 metres grading 0.38 gram per tonne gold and 55.1 grams per tonne silver in zone 1; and 99 metres grading 0.25 gram per tonne gold and 51.3 grams per tonne silver in zone 2. Intercepts are core lengths, not true widths.

The Capoose prospect is a low-grade "bulk silver" deposit. Church and Diakow (1982) have noted that the deposit type might be either porphyry or volcanogenic. Potassium-argon and galena lead isotope dating, fluid inclusions, oxygen isotopes, petrochemistry trace element analyses and garnet mineralogy currently being done at The University of British Columbia will help to define a genetic model for the deposit.

CONCLUSIONS

A unique combination of lithologies, textures, and mineralization is seen at Capoose. Some of the unusual features on the property include: garnet-rich rhyolites with alteration rims of quartz and muscovite; spherulite-like balls up to 30 centimetres in diameter occurring close to autobrecciated zones in rhyolite; belemnites in lithic wacke formed by reworking of pyroclastic materials. The origin of the garnet in rhyolite is important to developing an understanding of the genesis of the deposit. The intensity of pervasive phyllic alteration appears to be directly related to significant zones of precious metal mineralization. Although host lithologies appear to be Middle Jurassic, alteration and accompanying mineralization are not necessarily coeval.

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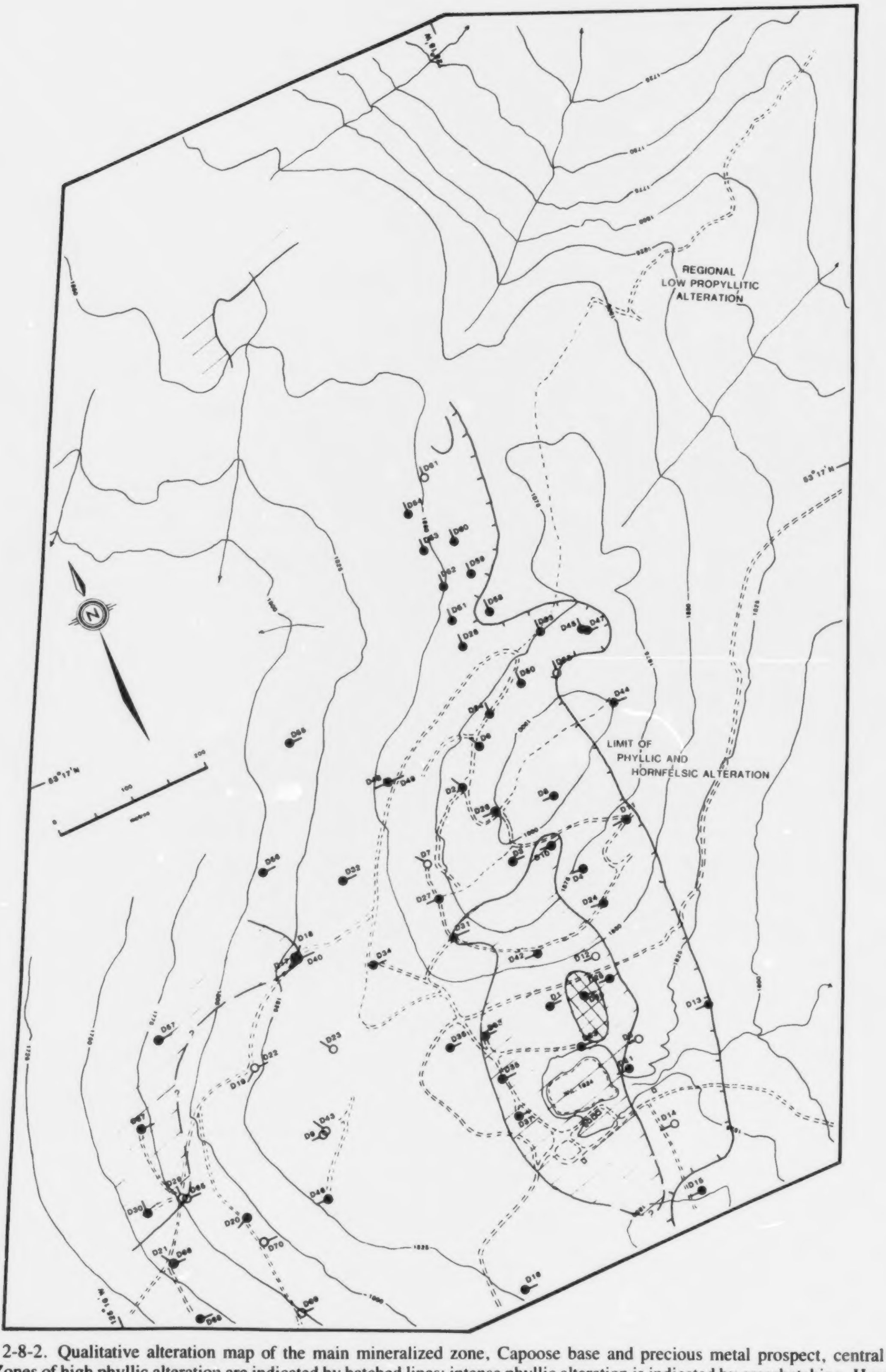
REGIONAL
LOW PROPYLLITIC
ALTERATION
LIMIT OF
PHYLLIC AND
HORNFELSIC ALTERATION
53°17'N
53°17'N
0
100
200
D61
D64
D63
D60
D62
D59
D51
D58
D28
D53
D45
D47
D40
D44
D6
D48
D8
D26
D7
D32
D27
D4
D24
D31
D34
D42
D12
D1
D13
D36
D14
D18
D40
D57
D22
D19
D23
D43
D9
D20
D70
D30
D16
1900
1875
1850
1825
1800
1775
1750
1725
1700

Figure 2-8-2. Qualitative alteration map of the main mineralized zone, Capoose base and precious metal prospect, central British Columbia. Zones of high phyllic alteration are indicated by hatched lines; intense phyllic alteration is indicated by crosshatching. Hornfelsing is observed in argillites and lithic wacke units (*see* Figure 2-8-1). Limit of hornfelsing and phyllic alteration is represented by heavy line with ties toward alteration. Propylitic alteration may be related to regional low-grade greenschist metamorphism rather than to propylitization peripheral to mineralization. (Note: solid drill holes indicate where information was available; open drill holes indicate no available information).

MULTI-ELEMENT LITHOGEOCHEMISTRY OF ALTERATION ASSOCIATED WITH GOLD-QUARTZ VEINS OF THE ERICKSON MINE, CASSIAR DISTRICT*

(104P/4)

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INTRODUCTION

The Erickson mine is 12 kilometres southeast of Cassiar (NTS 104P/4). Production commenced in December 1978 and averaged 170 tonnes per day at the end of 1984. Mill heads have averaged 14.3 grams gold per tonne and 12.8 grams silver per tonne. Total production to the end of 1984 was 4.03 million grams of gold and 3.23 million grams of silver from 274 530 tonnes milled.

Gold-silver-bearing white quartz veins occur in mafic volcanic, ultramafic and sedimentary rocks of the Sylvester Allochthon (Figure 2-9-2). Carbonate and less commonly carbon alteration envelopes are generally well developed at contacts of white quartz, carbon and layered dolomite veins with volcanic rocks. This paper presents a summary of the characteristics of the veins and alteration zones, the geochemistry of the alteration envelope and exploration guidelines.

VEINS

Two major groups of veins are observed in the Erickson mine (Figure 2-9-1); early gold-silver-bearing white quartz veins with associated carbon veins and late carbonate, clear quartz and pyrite veins. Early white quartz veins are the most common. Most are composed of white quartz with minor amounts of scattered ankerite (Bear, Devine, Dease, Goldie, Caitlin and the lower part of Jennie); some also contain carbon-rich layers (Alison, Maura and the upper part of Jennie). In addition, pyrite, tetrahedrite, chalcopyrite, sphalerite and gold may occur throughout white quartz veins. Fragments of carbonate and carbon-altered wallrock are occasionally present along vein margins.

Carbon veins are uncommon; they were noted only adjacent to the Alison and Maura veins. Carbon veins are composed of fine to coarse-grained massive carbon with lesser quartz and ankerite and traces of pyrite.

Late veins consist of layered dolomite, clear quartz, pyrite, white calcite and clear calcite. They comprise only a small portion of all veins in the mine. Layered dolomite veins, which usually contain minor quartz and pyrite, have only carbonate alteration envelopes associated with them. The McDame vein is an example of a large vein of this type.

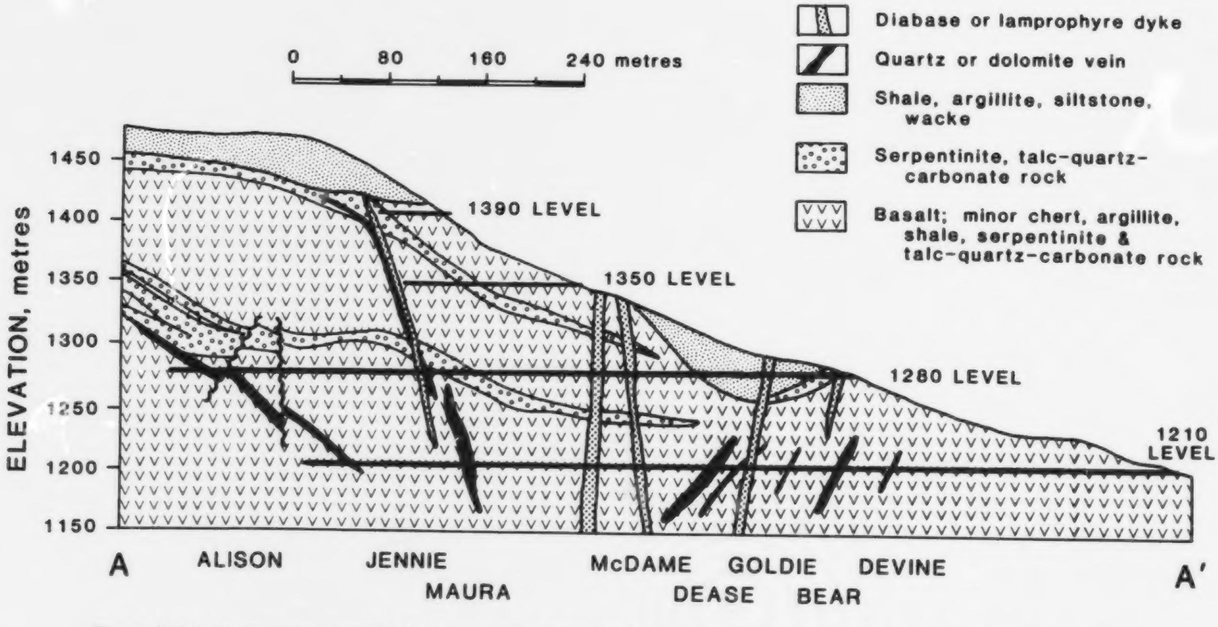
0
80
160
240 metres
Diabase or lamprophyre dyke
Quartz or dolomite vein
Shale, argillite, siltstone, wacke
Serpentinite, talc-quartz-carbonate rock
Basalt; minor chert, argillite, shale, serpentinite & talc-quartz-carbonate rock
ELEVATION, metres
1450
1400
1350
1300
1250
1200
1150
1390 LEVEL
1350 LEVEL
1280 LEVEL
1210 LEVEL
A
ALISON
JENNIE
MAURA
McDAME
GOLDIE
DEASE
DEVINE
BEAR
A'

Figure 2-9-1: Generalized geological cross-section of the Erickson mine, Cassiar district, showing the relation of veins to major rock units.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

ALTERATION ZONES

An idealized model of the vein-alteration envelope is illustrated in Figure 2-9-2. Typical cross sections through the vein-alteration envelopes in the mine are illustrated in the same diagram. Veins commonly range up to 5 metres in thickness and associated alteration envelopes may extend outward up to 40 metres, although 1 to 15 metres is common where volcanic material is the host.

The entire alteration envelope is generally divisible into two zones: an outer carbonate zone and an inner carbon zone. Each of the zones can be further subdivided. Fracture-controlled carbon alteration may be present in the carbonate zone and uncommonly in unaltered basalt. General descriptions of unaltered wallrock and the individual alteration zones are presented below, starting with the unaltered wallrock and progressing toward the vein. A summary of descriptions is provided in Table 2-9-1.

VOLCANIC COUNTRY ROCK

Volcanic country rocks are of basaltic composition; typically they are pale to dark green and weather dark green to black. Most exposures are aphanitic to medium-grained massive to pillowed rocks. Breccias and layered rocks are less common. A crosscutting network of dark green to black hairline fractures may be present, imparting a "crackled" texture to the rocks. Constituent minerals of the unaltered basalt include plagioclase, chlorite, actinolite, epidote, augite, calcite and titanium oxides. Quartz and disseminated pyrite may be present.

ALTERATION ZONE 2C — OUTER CARBONATE

Zone 2C marks the transition from country rock to carbonate-altered rock; it is typically pale green to buff and pale grey, weathers buff to orange-brown and may have a speckled or mottled appearance. Most of the altered volcanic rocks are fine to medium-grained and massive, although primary textures may be visible. A "crackled" texture, as previously described, may be superimposed on the rock. Mineralogically the zone is characterized by partial alteration of silicate minerals to ankerite, siderite, quartz and sericite. Titanium oxides, kaolinite, dolomite, pyrite, carbon and calcite may be present. The width of the outer zone is generally less than 1 metre, but may be much wider, especially if abundant stringer veins are present. The zone is present in the outer portion of most carbonate alteration envelopes.

ALTERATION ZONE 2B — INTERMEDIATE CARBONATE

Zone 2B consists of completely carbonate-altered volcanic rocks. Ghost textures may be present in coarser grained, layered and pillowed varieties. Rocks are buff to pale grey and weather orange-brown. Most are fine to medium-grained and massive. A "crackled" texture of black hairline fractures may be present locally. Constituent minerals include ankerite, siderite, quartz, sericite, titanium oxides and possibly kaolinite, dolomite, pyrite and carbon. Zone 2B is usually less than 10 metres wide and commonly occurs adjacent to white quartz and layered dolomite veins.

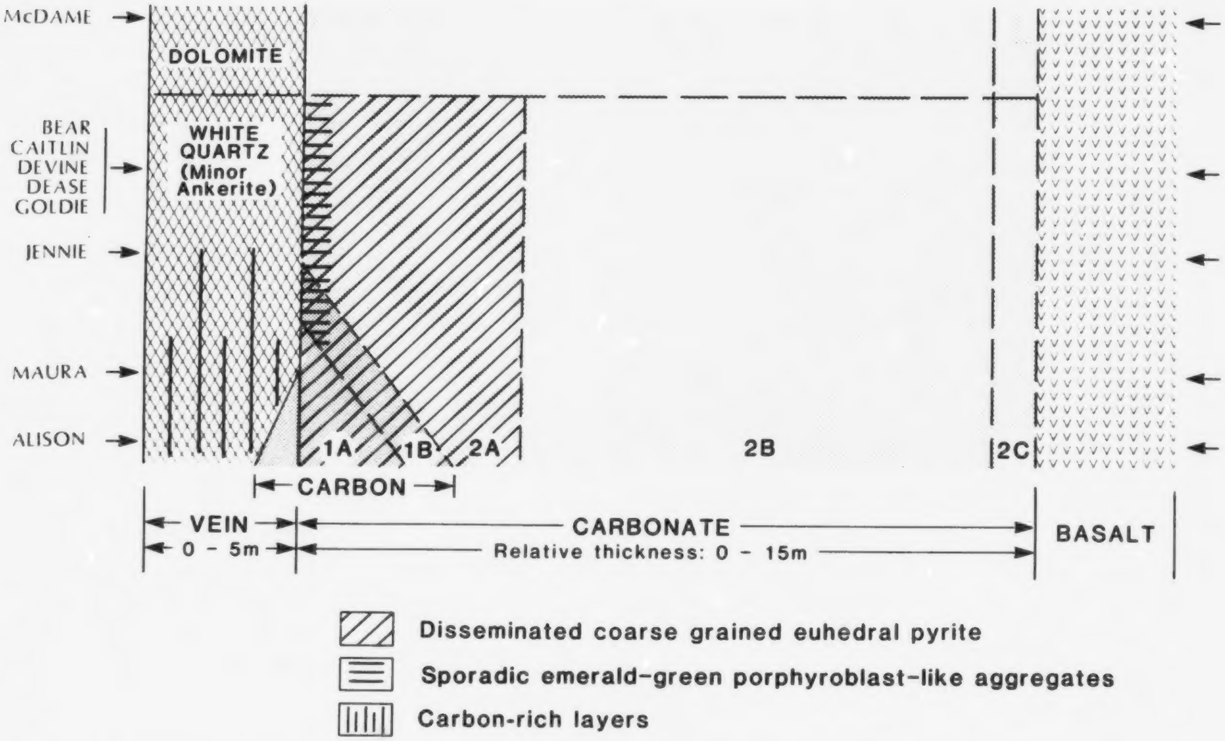

McDAME
BEAR
CAITLIN
DEVINE
DEASE
GOLDIE
JENNIE
MAURA
ALISON
DOLOMITE
WHITE QUARTZ (Minor Ankerite)
1A
1B
2A
2B
2C
CARBON
VEIN
0 - 5m
CARBONATE
Relative thickness: 0 - 15m
BASALT
▨ Disseminated coarse grained euhedral pyrite
☰ Sporadic emerald-green porphyroblast-like aggregates
▥ Carbon-rich layers

Figure 2-9-2: Hypothetical cross-section of idealized alteration envelopes enclosing white quartz, carbon and dolomite veins, Erickson gold mine, Cassiar district. Carbon vein and carbon alteration are shown as triangles to emphasize their local occurrence. Cross-sections characteristic of major veins are illustrated by the positions of vein names on the left. Alteration zones are: 1A — inner carbon, 1B — outer carbon, 2A — inner carbonate, 2B — intermediate carbonate, 2C — outer carbonate.

TABLE 2-9-1.
CHARACTERISTICS OF IDEAL ALTERATION ZONING RELATED TO WHITE QUARTZ, CARBON AND LAYERED DOLOMITE VEINS AT ERICKSON GOLD MINE

Zone	Thickness (m)	Occurrence	Colour	Mineralogy
basalt	—	country	pale to dark green	plagioclase, chlorite, actinolite, epidote, augite, calcite, titanium oxides ± pyrite, quartz
2C —	<1	very common	pale green to buff and pale grey	plagioclase, chlorite, ankerite, siderite, quartz, sericite, titanium oxides ± kaolinite, dolomite, pyrite, carbon, calcite, epidote, augite, actinolite
2B — intermediate carbonate	<10	very common	buff to pale grey	ankerite, siderite, quartz, sericite, titanium oxides ± kaolinite, dolomite, pyrite, carbon
2A — inner carbonate	<4	common	buff to pale grey with minor green mottling	ankerite, quartz, sericite, pyrite, titanium oxides ± siderite, carbon, arsenopyrite
1B — outer carbon	<1	uncommon	buff to black	ankerite, quartz, sericite, pyrite, titanium oxides, carbon ± siderite, arsenopyrite
1A — inner carbon	<3	uncommon	black	ankerite, quartz, sericite, carbon, pyrite, titanium oxides ± siderite, arsenopyrite

ALTERATION ZONE 2A — INNER CARBONATE

Zone 2A is similar to zone 2B with the following exceptions: the occurrence of coarse euhedral pyrite crystals, the presence of emerald green carbonate porphyroblasts, pistachio to lime green mottling and an increase in quartz content. Pyrite is more abundant closer to quartz veins. The carbonate porphyroblasts, less than 1 centimetre in diameter, occur sporadically only in the part of the zone adjacent to the contact with quartz veins. The pistachio to lime green mottling is uncommon; it also occurs adjacent to the contact with white quartz veins. Zone 2A is less than 4 metres wide and occurs only around white quartz veins.

ALTERATION ZONE 1B — OUTER CARBON

Zone 1B marks the transition from carbonate to carbon-altered rocks. The transition is gradational with colour changes from buff to black. The rocks are fine to medium-grained and massive. A "crackled" texture of black hairline fractures is common. Compositionally, the zone is characterized by ankerite, quartz, sericite, pyrite, titanium oxides and carbon. Siderite and arsenopyrite may also be present. Coarse euhedral pyrite crystals are scattered throughout the zone and concentrated closer to quartz veins. Zone 1B is not present in all alteration envelopes. It generally occurs associated with carbon and white quartz veins and is typically less than 1 metre wide.

ALTERATION ZONE 1A — INNER CARBON

Zone 1A is characterized by the presence of abundant carbon. Rocks are black, fine to medium grained and massive. Constituent minerals include ankerite, quartz, sericite, carbon, pyrite and titanium oxides. Siderite and arsenopyrite may also be present. Coarse euhedral pyrite crystals are scattered throughout the zone and concentrated closer to quartz veins. Zone 1A is uncommon; its occurrence is similar to zone 1B. It is generally less than 3 metres wide.

FRACTURE CONTROLLED CARBON ALTERATION

Fracture-controlled carbon alteration is characterized by an irregular network of black hairline fractures that impart a "crackled" texture to the rocks. Individual fractures are generally continuous. Oriented fractures that crudely divide the rock into elongate domains are locally common. Fractures are marked by the addition of very fine-grained carbon. A higher fracture density appears to be coincident with an increase in width of the carbon alteration around fractures. In areas of intense fracturing rocks resemble a breccia.

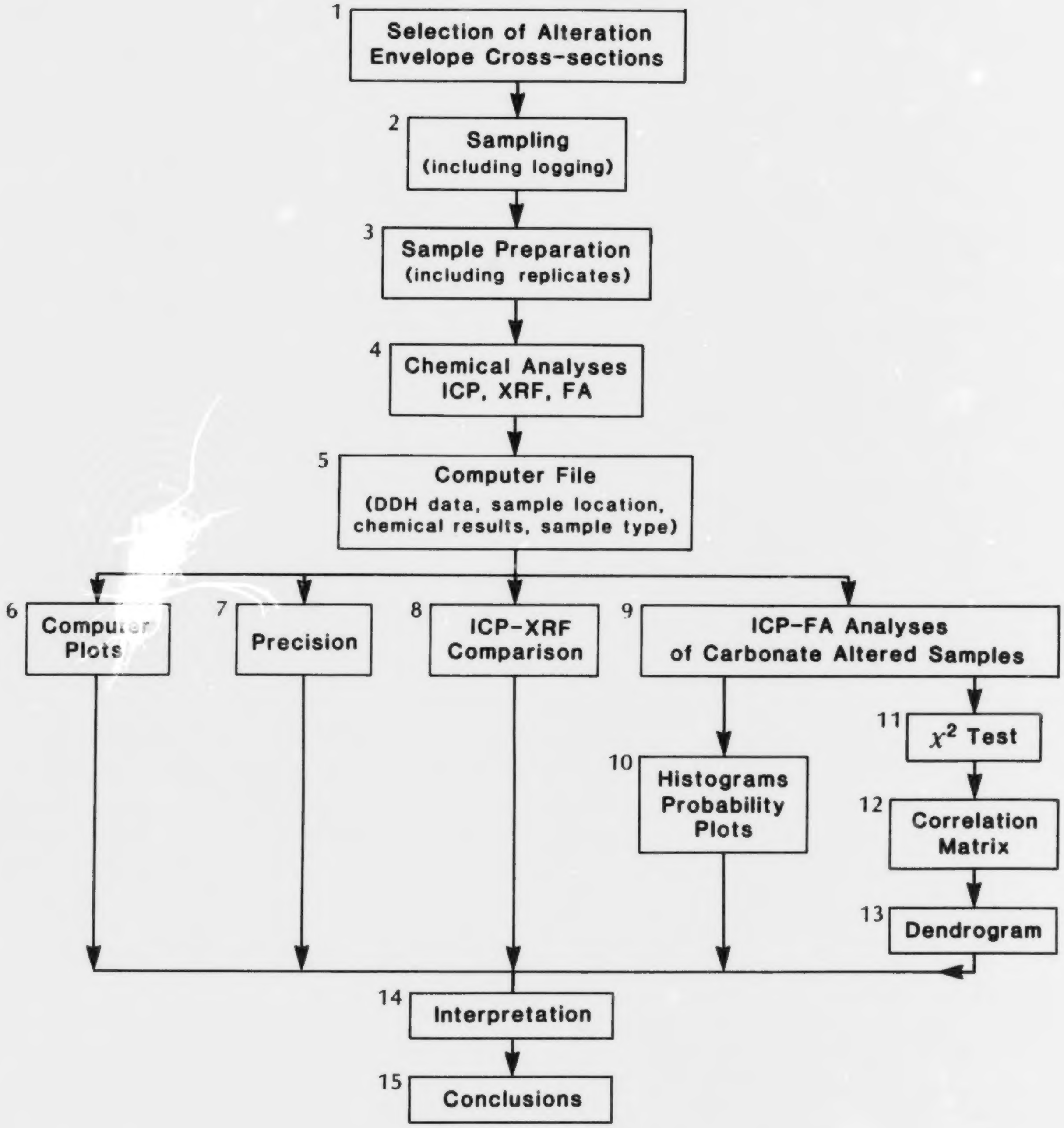
PYRITE

Pyrite occurs in variable amounts in all zones. Two types are noted: coarse-grained euhedral and fine-grained subhedral to anhedral pyrite. Concentration of coarse-grained pyrite increases up to 5 per cent toward quartz veins; crystal size also increases up to 5 millimetres in diameter. The distribution of fine-grained pyrite is erratic.

DISCUSSION

Systematic patterns within alteration envelopes vary little throughout the mine. The most important differences are the absence of specific zones and the variation in width and mineral abundances from one envelope to another. In general envelopes are nearly symmetrical, but in some cases the width in the hangingwall ranges up to twice that in the footwall. Hangingwall and footwall widths are generally from two to six times that of the adjacent vein. White quartz, and less commonly layered dolomite and carbon veins, generally occur in the core of alteration envelopes but are not always present.

Carbonate alteration envelopes surround all white quartz, layered dolomite and carbon veins; carbon alteration envelopes surround carbon veins and some white quartz veins. In general, auriferous white quartz veins are surrounded by all the carbonate alteration zones; carbon alteration zones may or may not be present. Layered dolomite veins are surrounded only by the intermediate and outer



1
Selection of Alteration Envelope Cross-sections
2
Sampling (including logging)
3
Sample Preparation (including replicates)
4
Chemical Analyses ICP, XRF, FA
5
Computer File (DDH data, sample location, chemical results, sample type)
6
Computer Plots
7
Precision
8
ICP-XRF Comparison
9
ICP-FA Analyses of Carbonate Altered Samples
10
Histograms Probability Plots
11
χ^2 Test
12
Correlation Matrix
13
Dendrogram
14
Interpretation
15
Conclusions

Figure 2-9-3: Flow diagram illustrating interpretive process for ICP-based lithogeochemical study of carbonate alteration haloes.

carbonate zones. The presence of the inner carbonate zone may therefore be used to identify carbonate alteration envelopes associated with potentially auriferous white quartz veins.

The presence of carbon alteration envelopes does not appear to have any bearing on the gold content of a quartz vein, but local concentrations of gold may be associated with carbon alteration. The occurrence of carbon alteration is probably related to nearby carbon-rich sedimentary rocks.

Carbonate and carbon alteration envelopes are composed mostly of carbonate with lesser quartz, sericite, kaolinite, titanium oxides, pyrite and carbon. In general, the rock is composed of approximately 55 per cent carbonate, 20 per cent quartz, 20 per cent sericite and kaolinite and 5 per cent titanium oxides, pyrite and carbon.

Carbonate minerals noted in the alteration envelopes are ankerite, siderite and dolomite. Ankerite occurs throughout all envelopes;

siderite is most common in the outer portion; dolomite is noted only in envelopes surrounding layered dolomite veins.

Kaolinite occurs throughout envelopes surrounding layered dolomite veins but only in the outer portion of some envelopes surrounding white quartz veins. Sericite occurs throughout envelopes surrounding white quartz veins.

The absence of dolomite and kaolinite and the presence of sericite in the inner portion of carbonate alteration envelopes provides a means of identifying envelopes associated with potentially auriferous white quartz veins.

GEOCHEMISTRY

The geochemical characteristics of carbonate alteration envelopes were investigated to test for patterns that might be useful as exploration guides. For the results of this orientation study to be of practical use, the following should apply:

(1) Sampling should conform to commonly used geochemical procedures.

(2) Multi-element analyses must be available commercially, at economic cost, and provide accurate results.

(3) Data interpretation procedures should be as simple as possible.

The procedures used in this study are presented in Figure 2-9-3 and discussed in the following sections.

SAMPLING AND ANALYSES

Seven carbonate and carbon alteration envelope cross-sections were selected from diamond-drill holes. Each was subdivided into 0.3 to 1.6-metre intervals of megascopically uniform character for sampling. Several intervals of the unaltered basalt surrounding each envelope were included where possible. A total of 106 samples of carbonate and carbon-altered basalt and 25 samples of unaltered basalt was collected. In addition 34 pulp samples of veins were retrieved from the Erickson mine laboratory for use in this study.

Loss-on-ignition (LOI) was determined for samples of altered and unaltered basalt. All samples were analysed for gold and silver by fire assay. All samples were digested with aqua regia solution and analysed for 30 elements by Inductively Coupled Plasma (ICP) spectroscopy. The 30 elements were: Al, Ti, Fe, Mn, Mg, Ca, Na, K, P, Au, Ag, As, Sb, Ba, B, Sr, Cu, Pb, Zn, Cd, Cr, Ni, Co, V, W, Mo, U, Th, La and Bi. Sixteen samples of altered basalt and six of unaltered basalt were also analysed by X-Ray Fluorescence (XRF) spectrometry for the following: SiO_2, Al_2O_3, TiO_2, Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, Ba, Sr, Rb, Zr, Y, Nb, Cu, Pb, Zn, Cr, Ni, Co, U and Mo.

COMPARISON OF ICP AND XRF DATA

ICP partial analyses and XRF total analyses from 22 samples of altered and unaltered basalt were compared by simple regression scatter plots using the following elements: Al, Ti, Fe, Mn, Mg, Ca, Na, K, P, Ba, Sr, Cu, Zn, Cr, Ni, Co and V. An example for calcium is shown in Figure 2-9-4. A least-squares line that passes through the origin was fitted to the data by regressing ICP on XRF analyses. The equation of the line and a linear correlation coefficient are included in Figure 2-9-4. The slope of the regression line provides an estimate of the average amount of an element released during digestion and detected by ICP analysis. The linear correlation coefficient is a measure of how well the ICP analyses reflect trends in the XRF analyses.

The average level of digestion and detection by ICP analyses is between 25 and 50 per cent for most elements; linear correlation coefficients range from 0.4 to 0.9. In general, results of the ICP-XRF comparison indicate that ICP partial analyses reflect trends shown in XRF total analyses reasonably well. This means that ICP partial analyses may be used as an economical analytical technique to obtain multi-element data for the purpose of a lithogeochemical survey. These data can then be examined for patterns that might be useful as exploration guides.

STATISTICAL ANALYSES OF ICP-FIRE ASSAY DATA

Only samples of carbonate-altered basalt analysed by ICP were used for statistical analysis. Gold and silver fire assay results were available and used in place of ICP results. A matrix of correlation coefficients was examined. Elements were divided into three groups: two with substantial intracorrelation and one without. Limited correlation exists between groups. Correlation measures for the first two groups are illustrated by a dendrogram in Figure 2-9-5.

The first group of elements (Ba, K, B, Sr, Al, Zn, Pb, Na, Cu, Au and As) are characterized by enrichment or depletion in carbonate alteration envelopes. The second group of elements (Cr, Ni, Mn, Mg, Ca, Fe and Co) are characteristically present in unaltered basalt and may be redistributed with enrichment adjacent to veins and depletion in the outer portion of the envelopes. Most of the third group of elements (Ag, Bi, Sb, U, V, W, Ti and Cd) are near or below detection limits; some may be enriched locally in alteration envelopes and the others lack discernible patterns. Four elements (La, Th, Mo and P) excluded from the matrix of correlation coefficients show patterns similar to the third group.

EXPLORATION PARAMETERS

Distribution patterns (Figure 2-9-6) for all elements were examined to determine those enriched in carbonate alteration envelopes surrounding auriferous white quartz veins. Potassium, barium, boron and arsenic show consistent and strong enrichment

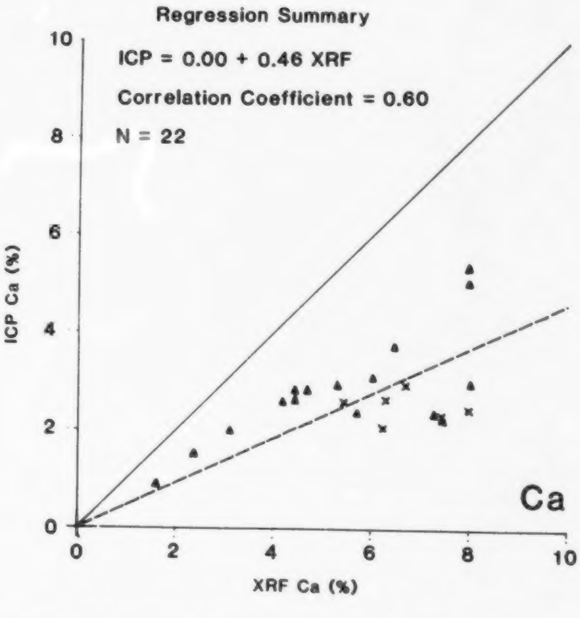


Figure 2-9-4: Plot of Inductively Coupled Plasma (ICP) partial analyses versus X-ray fluorescence (XRF) whole rock analyses for calcium in unaltered (Xs) and altered (open triangles) basalt, Erickson gold mine.

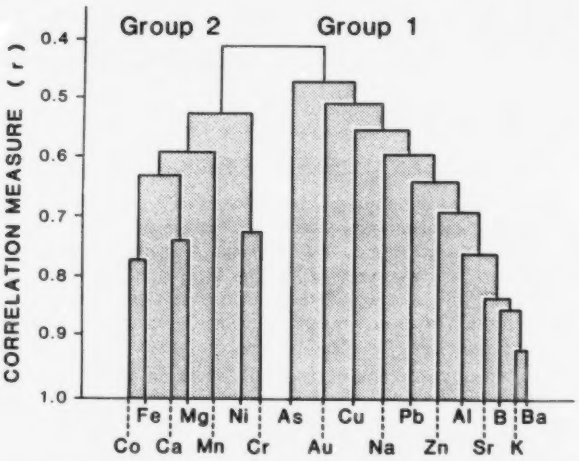


Figure 2-9-5: Dendrogram illustrating two principal intracorrelated grouping of elements based on ICP partial extraction data for Erickson gold mine.

throughout envelopes. Fire assay results for gold show enrichment in carbonate alteration envelopes adjacent to some veins, but ICP results do not as values are below the detection limit.

Copper, lead, zinc, antimony and silver are enriched in carbonate alteration envelopes surrounding auriferous quartz veins and occur in minerals associated with gold. Enrichment in copper, lead, zinc and antimony generally occurs immediately adjacent to auriferous white quartz veins. Copper enrichment is noted in most envelopes but enrichment of lead, zinc and antimony in only a few. Silver fire assay results are suspect because of their erratic nature and are of little practical use. Silver ICP analyses show enrichment adjacent to a few veins and may be useful.

Strontium, calcium, magnesium, iron and manganese are also enriched in carbonate-altered basalt adjacent to auriferous white quartz veins. These elements are associated with carbonate minerals. Because enrichment is due wholly or in part to redistribution within envelopes, these elements are not useful as exploration guides. Redistribution involves migration of bivalent metal cations from the outer portion of envelopes toward veins and combination with CO_2 to form carbonate minerals.

Thresholds of significance for selected elements enriched in envelopes surrounding auriferous quartz veins were determined from probability plots for multiple populations or from histograms and element profile plots for a single population. The thresholds are: K = 0.03 per cent, Ba = 90 ppm, B = 20 ppm, As = 15 ppm, Au = 1 ppb (0.03 ounce per ton), Ag = 1 ppm, Cu = 30 ppm, Pb = 9 ppm, Zn = 40 ppm and Sb = 4 ppm.

DISCUSSION

Enrichment in potassium, barium and boron reflects geological processes that are an inherent part of carbonate alteration in basalt surrounding auriferous white quartz veins. In contrast there appears to be no similar enrichment in carbonate alteration envelopes surrounding layered dolomite veins. Consequently enrichment in these elements is indicative of a carbonate alteration envelope that surrounds a potentially auriferous quartz vein. Arsenic, gold, silver, copper, lead, zinc or antimony enrichment, in addition to potassium, barium and boron, suggests that an alteration envelope probably surrounds an auriferous quartz vein that may also contain chalcopyrite, tetrahedrite, galena, sphalerite and arsenopyrite.

Application of the results of this orientation study to the Jennie vein is illustrated in Figure 2-9-6. Enrichment in potassium, barium, boron and arsenic characterizes the carbonate alteration envelope surrounding the vein. Enrichment in gold and copper in carbonate-altered basalt adjacent to the vein correlates with their occurrence in the vein. Zinc occurs only in the vein. Elevated antimony values occur in and adjacent to the stringer vein in the profile plot.

EXPLORATION GUIDELINES

A systematic examination of carbonate alteration envelopes for characteristics indicative of auriferous white quartz veins can be used as a guide to exploration. Assuming that diamond-drill core is being examined, the following steps are recommended:

(1) Log core and subdivide alteration envelope into zones.

(2) If a vein is not intersected in a carbonate alteration envelope, the presence of the inner carbonate zone indicates an auriferous white quartz vein may be present close by. Alternatively representative specimens of the inner portion of the envelope may be stained for dolomite and ankerite. The presence of dolomite indicates a layered dolomite vein. If dolomite is absent and ankerite present, the alteration envelope may contain an auriferous white quartz vein.

(3) Subdivide the zones into intervals of megascopically similar rock. Suggested sampling intervals are 0.5 metre for the inner carbonate zone and 10 metres for the intermediate and outer carbonate zones.

(4) Analyse for gold and silver by fire assaying. Analyse for potassium, barium, boron, arsenic, silver, copper, lead, zinc and antimony by ICP, following partial digestion with aqua regia solution.

(5) Plot results on graphs similar to those in Figure 2-9-6. Enrichment in potassium, barium and boron implies a potentially auriferous quartz vein is present. Enrichment in arsenic, gold, silver, copper, lead, zinc and antimony implies minerals containing these elements are probably also present in the vein.

ACKNOWLEDGMENTS

This work was supported by Erickson Gold Mines Ltd., North Vancouver, and The Natural Sciences and Engineering Research Council of Canada. The assistance of Mr. R. Somerville both in the field and through numerous discussions is particularly appreciated. Mr. G.H. Giroux provided assistance in obtaining computer output.

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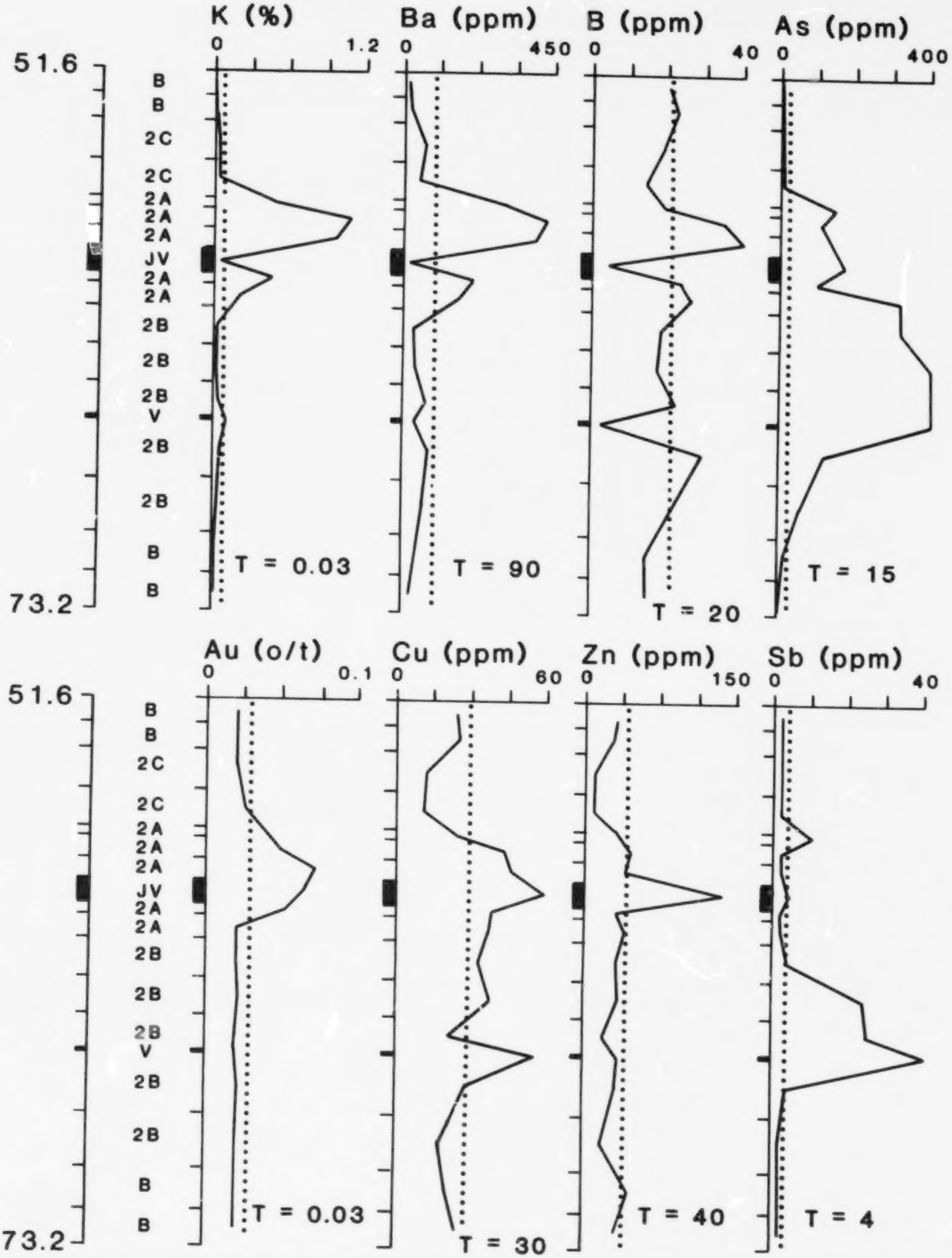

Figure 2-9-6: Element profiles across Jennie vein and adjacent altered and unaltered basalt, Erickson gold mine. Letter codes are: basalt (B), Jennie vein (JV), alteration zones (1B, 2A, etc.) as in Figure 2-9-2, thresholds between anomalous and background values (T).

THE GEOLOGY AND CONTROLS OF SKARN MINERALIZATION IN THE HEDLEY GOLD CAMP SOUTHERN BRITISH COLUMBIA*
(92H/8, 82E/5)

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INTRODUCTION

The current Hedley mapping project by the Ministry of Energy, Mines and Petroleum Resources is part of the joint Canada/British Columbia Mineral Development Agreement program. The objectives of the program are fully outlined by Ray *et al.* (1986), and include district-wide geological mapping at a field base map scale of 1:15 000.

The Hedley gold camp is situated approximately 40 kilometres east-southeast of Princeton, in southern British Columbia. The area has had a long history of gold mining and between 1902 and 1955 approximately 51 million grams (1.6 million ounces) of gold were won from several mineralized skarn orebodies (Table 2-10-1). Most production came from the Nickel Plate and Hedley Mascot mines (Mineral Inventory 92H/SE-038 and 036) located south of Lookout Mountain (Figure 2-10-1); total production from the smaller French, Canty, Good Hope and Banbury mines (MI 92H/SE-059, 064, 060 and 046 respectively) was approximately 1.8 million grams of gold (Table 2-10-1). Mineralization is also seen at the Peggy (Hedley Amalgamated) and Gold Hill properties (MI 92H/SE-066 and 054) (Figure 2-10-1).

The Hedley district was geologically mapped more than 40 years ago (Camsell, 1910; Bostock, 1930, 1940a, 1940b) but since that time little regional geological work has been done. The areas immediately surrounding some of the gold producers were mapped and studied in detail (Warren and Cummings, 1936; Dolmage and Brown, 1945; Lee, 1951), but less attention was devoted to either the regional geology or synthesising and comparing the various gold-bearing deposits in the district.

TABLE 2-10-1
PRODUCTION DATA, HEDLEY GOLD CAMP

Mine	MINFILE No.	Ore (Tonnes)	Gold (Grams)	Silver (Grams)	Reference
1. Nickel Plate	92H/SE-038				
1904-1963		2 978 046	41 637 105	4 163 138	National Mineral Inventory (NMI) 92H/8 — AU2
2. Hedley Mascot	92H/SE-036				
1936-1949		619 022	7 248 106	1 707 021	NMI 92H/8 — AU4
3. French	92H/SE-059				
1950-1955		29 450	786 420	NA	
1957-1961		48 158	817 306	65 784	NMI 92H/8 — AU1
Jan.-Apr. 1983		1 519	11 462	58 412	George Cross Newsletter, May 19, 1983
Total		79 127	1 615 188	124 196	
4. Canty	92H/SE-064				
1939, 1941		1 483	16 480	NA	NMI 92H/8 — AU5
5. Good Hope	92H/SE-060				
1946-1948		4 241	89 516	NA	NMI 92H/8 — AU3
1982		4 990	75 270	NA	
Total		9 231	164 786	NA	
6. Maple Leaf, Pine Knot Veins (Banbury Gold Mines)	92H/SE-046				
1937		5 897	29 424	13 375	NMI 92H/8 — AU7
1982		1 179	4 124	NA	
Total		7 076	33 548	13 375	
Total Production		3 693 985	50 715 213	6 007 730	

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

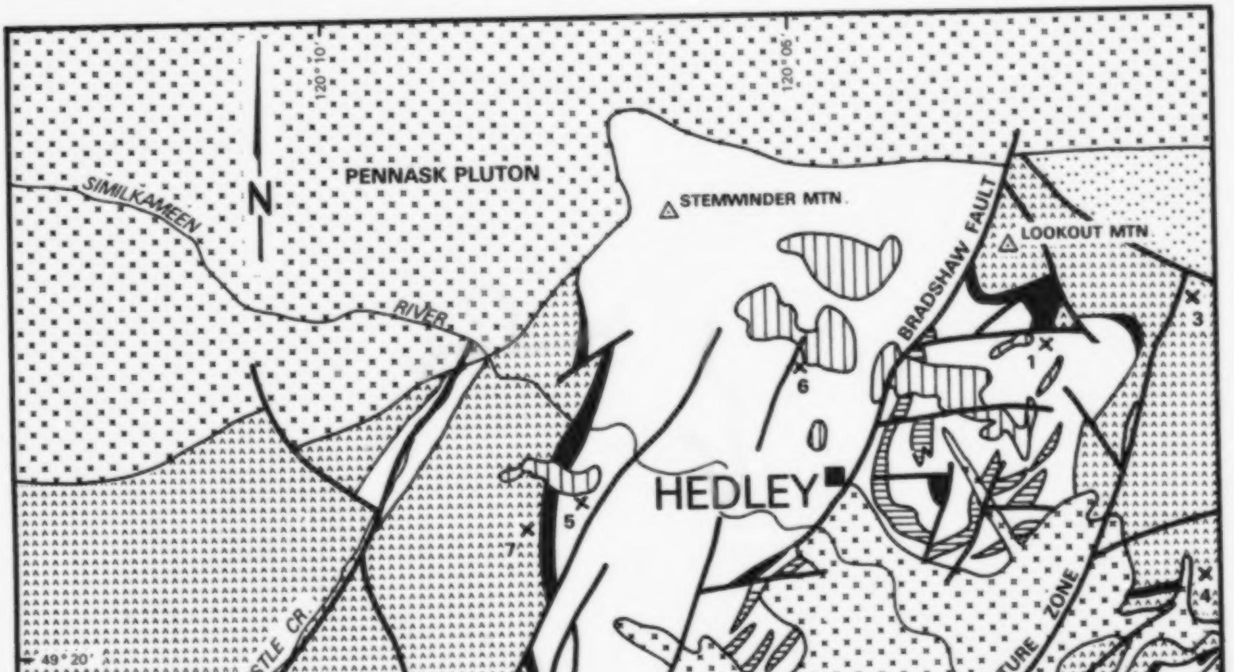
120°10'
120°06'
N
PENNASK PLUTON
SIMILKAMEEN
RIVER
STEMWINDER MTN.
LOOKOUT MTN.
BRADSHAW FAULT
3
1
6
HEDLEY
5
7
4
2
49°20'
WHISTLE CR.
CAHILL CREEK FRACTURE ZONE
WINTERS CR.
CAHILL CREEK PLUTON
ASHNOLA HILL
0
2
Kilometres

Figure 2-10-1. Geology of the Hedley area.

LEGEND

QUARTZ PORPHYRY

▩

SIMILKAMEEN INTRUSIONS

⁙ *Granodiorite, granite (c.150 Ma)*

HEDLEY INTRUSIONS

▥ *Diorite, Gabbro (c.180 Ma)*

ROCKS OF UNCERTAIN AGE

░ *Dacitic and andesitic tuffs (Units B and C)*

UPPER TRIASSIC — WHISTLE CREEK SEQUENCE

▲ *Tuff, volcanic breccia, siltstone (Unit A)*

■ *Copperfield conglomerate — limestone boulder conglomerate*

UPPER TRIASSIC — HEDLEY SEQUENCE

□ *Siltstone, argillite, minor limestone and conglomerate*

▤ *Limestone*

PALEOZOIC — APEX MOUNTAIN GROUP

▨ *Argillite, chert, greenstone tuff, minor limestone*

GOLD BEARING PROPERTIES

LOCATION NO.	NAME AND MINFILE NO.
1.	NICKEL PLATE AND MASCOT MINE (92H/SE-38,36)
2.	FRENCH MINE (92H/SE-59)
3.	CANTY MINE (92H/SE-64)
4.	GOOD HOPE MINE (92H/SE-60)
5.	BANBURY GOLD MINE (92H/SE-46)
6.	PEGGY/HEDLEY AMALGAMATED (92H/SE-66)
7.	GOLD HILL (92H/SE-54)

BRITISH
COLUMBIA
STUDY AREA

Interest in the Hedley gold camp has recently revived due to Mascot Gold Mines Limited planned 1987 reopening of the Nickel Plate mine as an open-pit operation (Simpson and Ray, 1986). Current open-pit reserves total approximately 6.5 million tonnes of ore grading 5.1 grams gold per tonne.

DISTRICT GEOLOGY

The Hedley region lies within the Intermontane Belt of the Canadian Cordillera, and the overall geology of the district is presented in Figure 2-10-1. A highly deformed package of cherts, argillites, tuffaceous siltstones, greenstones and minor limestones, originally subdivided into the Independence, Bradshaw, Old Tom and Shoemaker Formations (Bostock, 1940a; Little, 1961) outcrops in the southeast portion of the area and east of Winters Creek (Figure 2-10-1). In more recent work, Milford (1984) grouped these formations into the Apex Mountain Group; Upper Devonian, Carboniferous and Middle to Late Triassic microfossils have been recovered from some units in the Apex Mountain Group (Milford, 1984; J.W.H. Monger, personal communication, 1985). The relationship between the group and the supracrustal rock units further west is uncertain, however the Apex Mountain Group is believed to represent a highly deformed ophiolite complex that formed above an easterly dipping subduction zone (Milford, 1984).

The area between Winters Creek and Whistle Creek (Figure 2-10-1) is largely underlain by a 1000 to 2000-metre-thick sedimentary and volcaniclastic package belonging in part to the Upper Triassic Nicola Group (Rice, 1947). This package has been subdivided by previous workers into numerous formations (*see* Rice, 1947, page 13); our preliminary work indicates that the package can be informally separated into a younger Whistle Creek sequence to the west and an older Hedley sequence to the east (Figures 2-10-1 and 2-10-2). The latter comprises a generally westerly dipping, 450 to 600-metre-thick succession of sedimentary rocks that are characterized by thin-bedded, calcareous and cherty turbiditic siltstones (Plate 2-10-1), black argillites and impure limestone beds of variable thickness. Some parts of the Hedley sequence, particularly its upper portion, contain appreciable amounts of fine-grained volcaniclastic and crystal tuff material. Numerous limestone samples collected from the sequence by J.W.H. Monger and D. Tempelman-Kluit of the Geological Survey of Canada and by the present authors yielded conodonts of Carnian to Early Norian age (M.J. Orchard, personal communication, 1985, 1986).

An east-west facies change is recognized in the Hedley sequence and is believed to reflect an original, tectonically controlled, westerly sloping basin margin. West of the Bradshaw fault (Figure 2-10-1) the sequence comprises deeper water black argillites, distal turbiditic siltstones (Plate 2-10-1) and dark impure limestone beds that seldom exceed 5 metres in thickness. East and southeast of the fault however, (Figure 2-10-1) the sedimentary rocks indicate deposition in a more proximal, shallower marine, possibly fore-reef environment. This proximal succession includes turbiditic siltstones, wackes and minor impersistent grit and chert pebble conglomerate horizons, as well as massive to conglomeratic reefal limestone beds that locally exceed 75 metres in thickness. One limestone-rich unit, the "Sunnyside limestone", is traceable discontinuously for several kilometres along strike between Hedley township and the Nickel Plate mine (Camsell, 1910; Bostock, 1930, 1940a). The siltstones and thick, massive limestone beds east of Ashnola Hill* (Figure 2-10-1) represent a southern extension of the shallow marine facies of the Hedley sequence.

The Hedley sequence passes stratigraphically upwards into the 700 to 1200-metre-thick Whistle Creek sequence (Figures 2-10-2 and 2-10-3). This forms a generally westerly dipping, west-facing succession that mainly underlies the western portion of the district although small, downfaulted outliers of the sequence are present east of Hedley township and in the vicinity of Lookout Mountain (Figure 2-10-1). It contains tuffaceous siltstones and rare argillites in its lower portion, but higher in the succession is characterized by bedded to massive ash and lapilli tuffs with minor volcanic breccia.

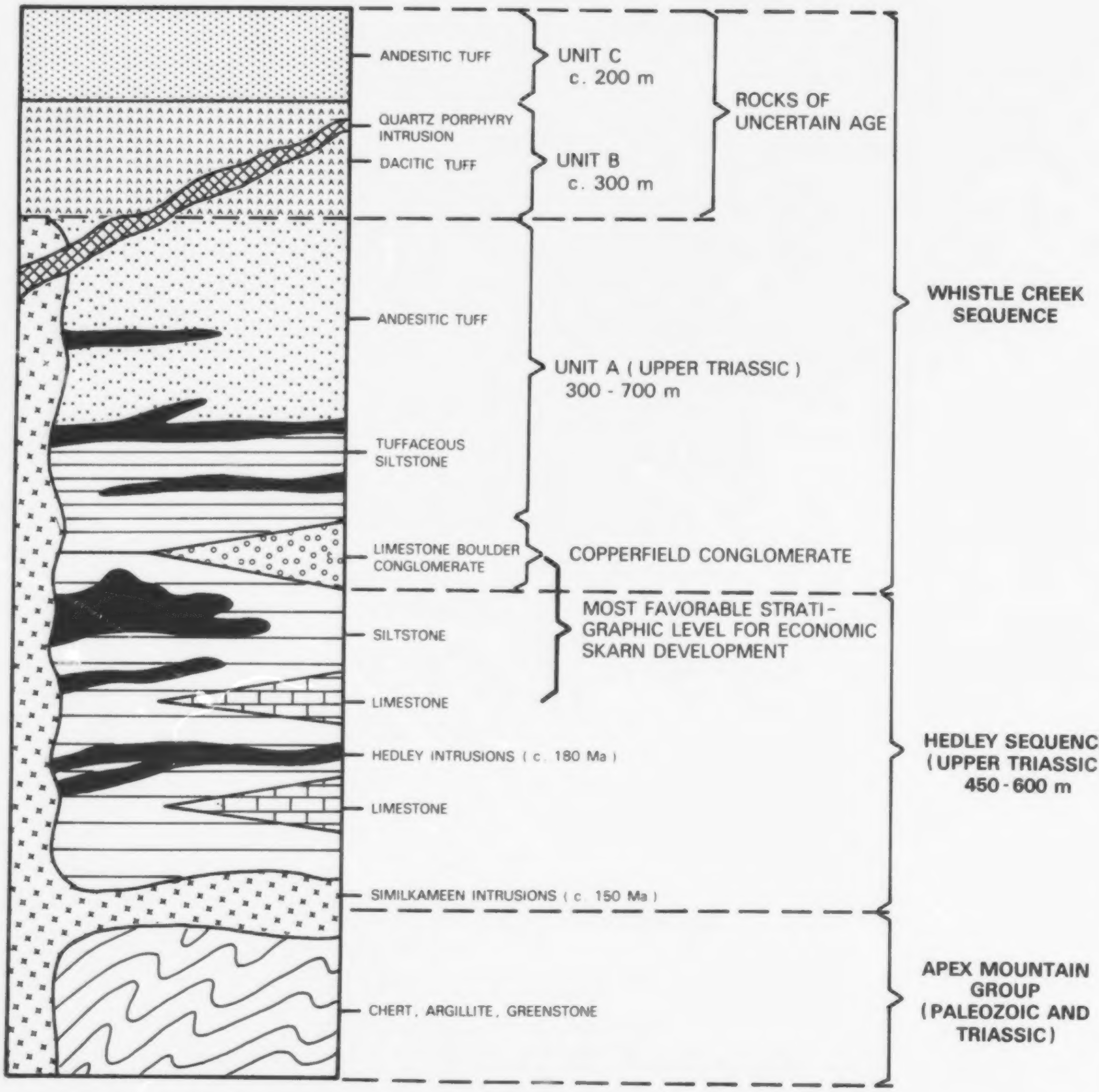
ANDESITIC TUFF
UNIT C
c. 200 m
QUARTZ PORPHYRY INTRUSION
ROCKS OF UNCERTAIN AGE
DACITIC TUFF
UNIT B
c. 300 m
ANDESITIC TUFF
WHISTLE CREEK SEQUENCE
UNIT A (UPPER TRIASSIC)
300 - 700 m
TUFFACEOUS SILTSTONE
LIMESTONE BOULDER CONGLOMERATE
COPPERFIELD CONGLOMERATE
MOST FAVORABLE STRATIGRAPHIC LEVEL FOR ECONOMIC SKARN DEVELOPMENT
SILTSTONE
LIMESTONE
HEDLEY INTRUSIONS (c. 180 Ma)
HEDLEY SEQUENCE (UPPER TRIASSIC) 450 - 600 m
LIMESTONE
SIMILKAMEEN INTRUSIONS (c. 150 Ma)
APEX MOUNTAIN GROUP (PALEOZOIC AND TRIASSIC)
CHERT, ARGILLITE, GREENSTONE

Figure 2-10-2. Schematic section illustrating the stratigraphy of the Hedley area.

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* Ashnola Hill is an unofficial name given to the hill surmounted by the British Columbia Telephone Company microwave tower.

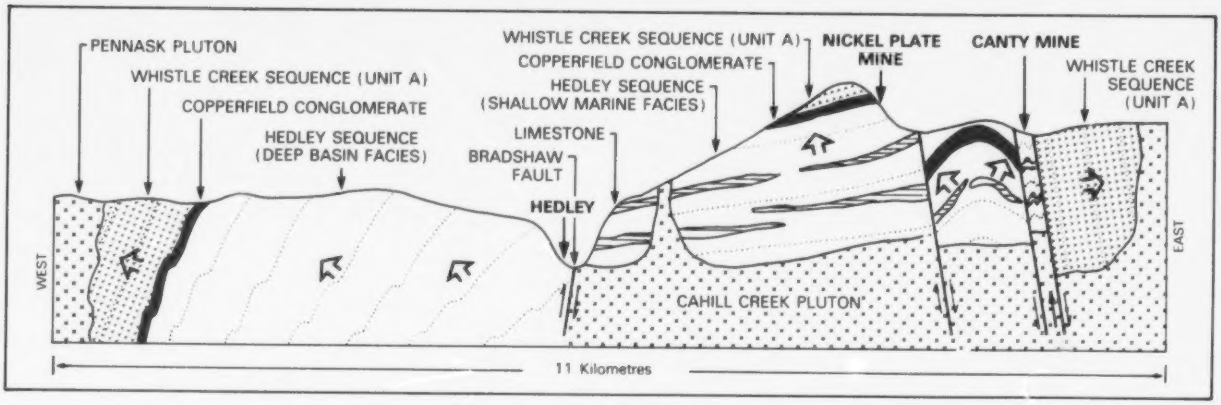

PENNASK PLUTON
WHISTLE CREEK SEQUENCE (UNIT A)
COPPERFIELD CONGLOMERATE
HEDLEY SEQUENCE (DEEP BASIN FACIES)
WHISTLE CREEK SEQUENCE (UNIT A)
COPPERFIELD CONGLOMERATE
HEDLEY SEQUENCE (SHALLOW MARINE FACIES)
LIMESTONE
BRADSHAW FAULT
HEDLEY
NICKEL PLATE MINE
CANTY MINE
WHISTLE CREEK SEQUENCE (UNIT A)
CAHILL CREEK PLUTON
WEST
EAST
11 Kilometres

Figure 2-10-3. Schematic east-west geological section, north of the Similkameen Valley, across the Hedley area.

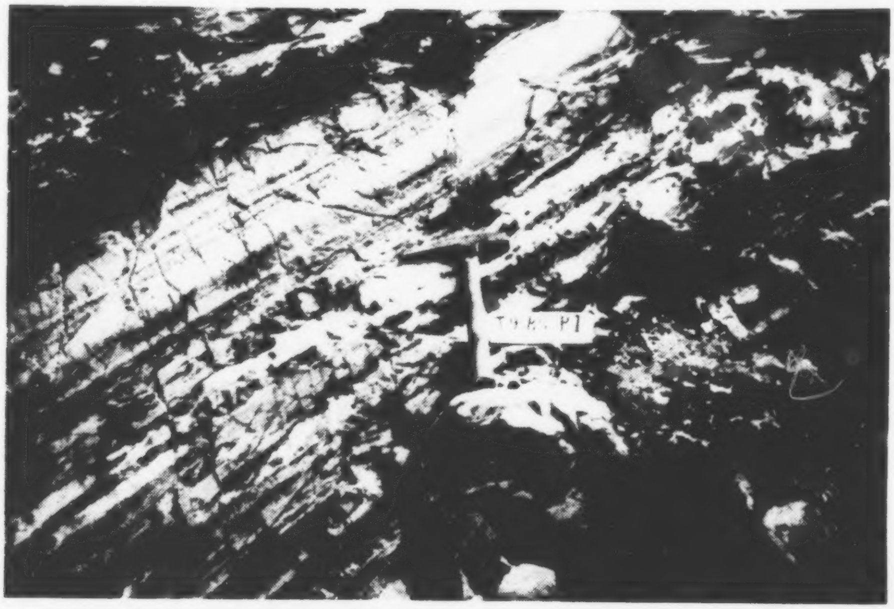


Plate 2-10-1. Thin-bedded turbiditic siltstones of the Hedley sequence (deeper water facies) with some graded beds; 1 kilometre west of Hedley township.

Plate 2-10-2. Limestone-boulder-bearing Copperfield conglomerate; 0.6 kilometre west of Henri Creek.

The Whistle Creek sequence is distinguished from the underlying rocks by a general lack of limestones and a predominance of volcaniclastic material. No volcanic flows have been identified in the sequence.

The Whistle Creek sequence is divisible into three stratigraphic units, the oldest (Unit A, Figure 2-10-2) is believed to be Late Triassic in age, while the precise age of the upper two younger units (Units B and C, Figure 2-10-2) is uncertain. Unit A is mainly comprised of well-bedded to massive ash tuffs of andesitic to basaltic composition. In its lower portion the unit is predominantly sedimentary in character and includes tuffaceous siltstones, interbedded with thin horizons of well-bedded to massive crystal-lithic tuff. Higher in the unit, ash tuffs with minor lapilli tuffs and volcanic breccias predominate; individual horizons are thicker and more massive, and sedimentary bedding is uncommon. Thin-section studies reveal that many ash tuffs in Unit A contain abundant euhedral, pristine crystals of plagioclase and pyroxene that show little evidence of mechanical abrasion or transportation.

The stratigraphically overlying Unit B which underlies the area northeast of Lookout Mountain and also outcrops in the vicinity of Ashnola Hill (Figure 2-10-1) has a maximum thickness of approximately 300 metres. It is characterized by massive, grey-coloured ash tuffs of probable dacitic composition. These tuffs carry well-rounded, partially resorbed, volcanogenic quartz crystals and locally contain angular lapilli of dacite, rhyolite and quartz porphyry. At one locality close to Ashnola Hill these rocks are maroon coloured and contain flattened, possibly welded pumice fragments suggesting subaerial deposition.

The youngest rocks in the Hedley sequence (Unit C, Figure 2-10-2) are confined to the southern part of the area, southwest of Ashnola Hill, and have an estimated thickness of 200 metres. They comprise mainly fresh, massive, dark green crystal-lithic tuffs of andesitic to basaltic composition, many of which are characterized by abundant large, euhedral plagioclase crystals.

The Whistle Creek and Hedley sequences are separated by a limestone boulder conglomerate (Figure 2-10-2; Plate 2-10-2) which forms the most distinctive and important stratigraphic marker horizon in the district. This conglomerate is best developed west of Hedley where it forms a northerly trending, steeply dipping unit that is traceable discontinuously for over 15 kilometres along strike (Figure 2-10-1). Remnant outliers of the same conglomerate are also seen further east, in the Nickel Plate mine-Lookout Mountain vicinity, where it was originally called the "Copperfield breccia" (Camsell, 1910; Bostock, 1930; Billingsley and Hume, 1941). During preliminary regional mapping work (Ray *et al.*, 1986) this unit was informally called the "Henri Creek conglomerate"; due to precedence, it is now informally renamed the "Copperfield conglomerate".

The Copperfield conglomerate is best developed and exposed west and northwest of the Banbury Gold Mines property (Figure 2-10-1) where it reaches its maximum thickness of 200 metres. Elsewhere, it is often less than 10 metres thick, but is well developed south of Lookout Mountain (100 metres thick), and southeast of Ashnola Hill (70 metres thick). The conglomerate varies from clast to matrix-supported and is characterized by abundant, well-rounded to angular pebbles, cobbles, and boulders of limestone generally up to 1 metre in diameter (Plate 2-10-2). In some localities, rare limestone blocks and olistoliths up to 15 metres in diameter are present, usually at the stratigraphic base of the conglomerate. Limestone generally comprises more than 95 per cent of the clasts but rare clasts of argillite, siltstone, wacke, chert, crystalline quartz, and both felsic plutonic and acid to intermediate volcanic rocks are also present. The limestone clasts vary considerably in appearance, from grey to buff to pink in colour, from fine to coarse grained, and from massive to thin-bedded. Some limestone boulders contain fragments of bivalve shells and crinoid stems, and a few are composed of a limestone conglomerate comprising grey limestone clasts cemented in a calcareous matrix. Other less common boulders consist of chert pebble conglomerate with a gritty calcareous matrix.

Some of the larger, elongate, siltstone clasts are deformed and exhibit soft sediment deformation structures, suggesting that they were unlithified when incorporated into the conglomerate. The conglomerate throughout the district exhibits both normal and reverse grading; larger blocks and boulders are generally more common towards the stratigraphic base, and finer grained, moderately bedded grits and conglomerates are found towards the top of the unit. The conglomerate matrix varies from massive to thin-bedded and ranges from siliceous and gritty to calcareous or finely tuffaceous; locally it shows evidence of chaotic slumping and soft sediment disruption. Conodonts extracted from some limestone boulders give Carnian ages (J.W.H. Monger and M.J. Orchard, personal communication, 1985, 1986), while radiolarians of Permian age were extracted from one chert pebble (F. Cordey, personal communication, 1985).

The Copperfield conglomerate is interpreted to be an olistostrome. It probably resulted from the catastrophic slumping of an unstable accumulation of reef debris down a steep submarine slope, and the widespread chaotic deposition of this mass onto a sequence of unlithified, deeper water turbidites. South of Lookout Mountain (Figure 2-10-1) some of the larger limestone blocks were apparently autobrecciated during the downslope movement. They are now represented by highly angular, closely interlocking fragments, separated by a thin limy gouge matrix.

Sedimentary indicators show that the Hedley and Whistle Creek sequences generally young westward (Figure 2-10-3). Measurements of crossbeds and flame structures indicate that the Hedley sequence, and Unit A of the Whistle Creek sequence were deposited by northwesterly to southwesterly directed paleocurrents.

Three plutonic suites are recognized in the area (Figure 2-10-1). The oldest is probably Middle Jurassic in age and comprises massive, coarse-grained, hornblende-bearing diorites (Plate 2-10-3), quartz diorites and minor gabbros of the Hedley intrusions (Rice, 1947). Potassium-argon age dates from these rocks range between 170 and 190 million years (Roddick *et al.*, 1972). These rocks form major stocks up to 1.5 kilometres in diameter and swarms of thin sills and dykes, up to 200 metres in thickness and over 1 kilometre in strike length. The suite is absent in the Apex Mountain Group, but further west is widespread throughout the Upper Triassic rocks in the Hedley district. Most of the Hedley intrusions are concentrated along a northerly trending, elongate zone that coincides with the slope-related change of sedimentary facies in the Hedley sequence. Varying degrees of sulphide-bearing skarn alteration are developed within and adjacent to many of these intrusions. Some previous workers (Billingsley and Hume, 1941; Dolmage and Brown, 1945) considered this plutonic suite to be genetically related to the skarn-hosted gold mineralization in the district, including that at the Nickel Plate, Hedley Mascot and French mines (Figure 2-10-1). The preliminary geochemical and mapping results of this project support their conclusions.

The second plutonic suite, the Similkameen intrusions, comprises coarse, massive, biotite ± hornblende-bearing granodiorite of presumed Late Jurassic age; most potassium-argon ages from these rocks range from 150 to 160 million years (Roddick *et al.*, 1972). These intrusions generally form large bodies such as the Pennask pluton which outcrops northwest of Hedley and a granodiorite body outcropping between Winters Creek and Hedley township (Figure 2-10-1). This body, and others of its type in the region, have been given a variety of sometimes conflicting names (Roddick *et al.*, 1972; Peto and Armstrong, 1976), but is here informally named the "Cahill Creek pluton" (Figure 2-10-1). It intrudes both the Whistle Creek and Hedley sequences, and separates these rocks from the more highly deformed ophiolitic complex of the Apex Mountain Group further to the southeast (Figure 2-10-1). North of Ashnola Hill an 8-kilometre-long, dyke-like apophysis from the pluton has been controlled by a west-southwesterly extension of the Cahill Creek fracture zone (Figure 2-10-1). Country rocks up to 1.5 kilometres from the margins of the younger Similkameen intrusions are commonly hornfelsed; some minor second generation skarn alteration is also locally present adjacent to the Cahill Creek pluton, but it is generally sulphide poor and not auriferous. Unlike the biotite hornfelsed Hedley and Whistle Creek sequences, the Apex Mountain Group rocks within the contact aureole of the Cahill Creek pluton are distinct in containing abundant cordierite.

Several extensive roof pendants of hornfelsed, highly deformed sedimentary and tuffaceous rocks are present in the Cahill Creek pluton north of Winters Creek (Figure 2-10-1). These pendants contain coarse volcanic breccias, minor chert pebble conglomerates, limestones, siltstones and a thick horizon of limestone boulder conglomerate. The boulder conglomerate is the principal host for auriferous skarn mineralization at the French mine and closely resembles the Copperfield conglomerate seen further west. However it is not known whether these two conglomerate units are

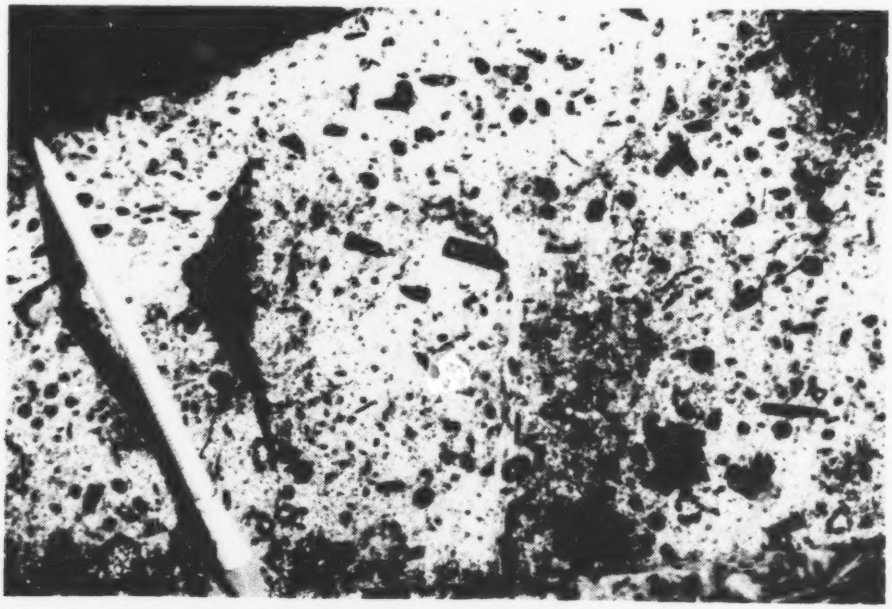


Plate 2-10-3. Dioritic Hedley intrusions with large hornblende phenocrysts. Part of a large sill that intrudes the Hedley sequence 2 kilometres north of Hedley township.

stratigraphically equivalent. The precise relationship between the deformed and hornfelsed roof pendant geology in the French mine area and the stratigraphic succession recognized further west is uncertain.

The third and youngest intrusive suite in the district is represented by a fine-grained, felsic, quartz-bearing porphyry that cuts and postdates the Cahill Creek pluton (Figure 2-10-2). These rocks are characteristically leucocratic and contain rounded, partially resorbed quartz phenocrysts up to 4 millimetres in diameter. Sills and dykes, generally less than 3 metres wide, are widespread but not abundant throughout the area. West of Ashnola Hill one 200-metre-wide, 1.3-kilometre-long dyke-like body of quartz porphyry is controlled by the west-southwest-trending Cahill Creek fracture zone (Figure 2-10-1).

The ages of Units B and C of the Whistle Creek sequence are problematic (Figure 2-10-2). They may represent a part of the Upper Triassic succession conformably overlying the Unit A rocks. However, some distinctive features suggest they could be younger and possibly equivalent in age to the Cretaceous Kingsvale or Spences Bridge Group, as first suggested by J.W.H. Monger (personal communication, 1985). These features include:

(1) The generally very fresh appearance of Units B and C,

(2) The unusual quartz-bearing and dacitic composition of Unit B, compared to the characteristic andesitic-basaltic composition of the Nicola Group tuffs further west (Preto, 1979),

(3) The common presence of Hedley intrusions in Unit A and their apparent absence in Units B and C, and

(4) The similarity between the resorbed quartz crystals in Unit B and those in the large, post-Mid-Jurassic quartz porphyry dyke near Ashnola Hill raises the possibility that these young intrusions were feeders for the Unit B volcaniclastic rocks. This age problem should be resolved by current uranium-lead dating.

Parts of Units B and C are weakly altered to skarn and if a Cretaceous age were proved for these rocks, it would indicate the existence of a third generation of skarning in the district. This alteration differs from other skarns and is typified by abundant epidote, minor amounts of small, bright red, euhedral garnets and no apparent gold.

GEOLOGICAL HISTORY OF THE AREA

The postulated early history of the area is illustrated in Figures 2-10-4A to 2-10-4D. The Late Triassic sedimentary Hedley sequence was deposited by westerly directed paleocurrents down a westerly inclined basin margin slope. This resulted in the sedimentary facies changes in the sequence with deeper water marine turbidites and thin limestone beds in the west, and shallow water marine reefal limestones and conglomeratic units in the east (Figure 2-10-4A). The basin margin slope was probably controlled by a northerly trending structure related to a major flexure within the underlying basement rocks, which are not exposed in the area (Figures 2-10-4A and 2-10-4B). The Hedley sequence sedimentation was succeeded by the catastrophic and widespread deposition of the Copperfield conglomerate across the area (Figure 2-10-4B). The appearance of this unit marks a profound change in the sedimentary environment and may reflect the sudden collapse of the basin due to regional plate movements related to the initiation of the Nicola arc further to the west.

Deposition of the Copperfield conglomerate was followed by thick airfalls of andesitic ash tuffs that immediately resulted in conditions totally unsuited to limestone development. This andesitic volcaniclastic episode was responsible for the deposition of Unit A of the Whistle Creek sequence (Figures 2-10-2 and 2-10-4C). Field data suggest that westerly directed paleocurrents still prevailed during the initial deposition of Unit A (Figure 2-10-4C). However, it is uncertain whether the andesitic airfall material was derived from the Nicola arc to the west, or from a volcanic source to the east. Initially, deposition of the Whistle Creek sequence was predominantly sedimentary in character; the tuffs are well bedded and interlayered with substantial amounts of turbiditic sediment. Higher up in the Unit A succession however, the volcaniclastic components dominate, leading to the deposition of thick, massive tuffs that rarely contain either bedding or sedimentary horizons. Although the basin continued to slowly subside at this time, there is no evidence of an east-to-west facies change in Unit A of the Whistle Creek sequence (Figure 2-10-4C).

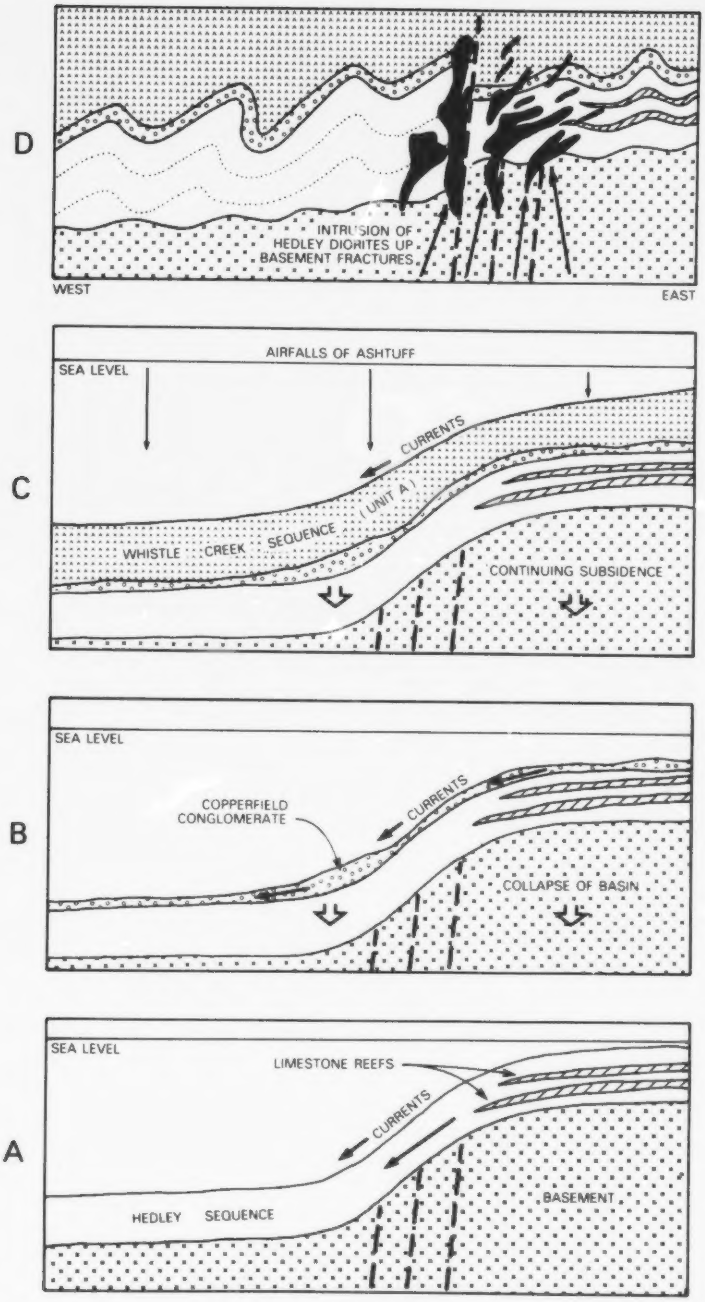
Deposition of the Whistle Creek (Unit A) sequence was followed by a period of deformation accompanied initially by the emplacement of the Mid-Jurassic Hedley intrusions. These possibly resulted from melting in the basement during reactivation and deformation along the older basement flexure (Figure 2-10-4D). The melts moved upwards into the overlying Upper Triassic cover rocks and were emplaced as stocks, dykes and sills throughout the district. However most of the dioritic intrusive swarms were concentrated in the cover rocks along a northerly trending zone above the reactivated basement flexure (Figure 2-10-4D).

Following Mid-Jurassic dioritic plutonism, the sedimentary rocks were deformed into upright to asymmetric to overturned folds with northerly striking axial planes. This regional deformation terminated with the Late Jurassic emplacement of the Pennask and Cahill Creek plutons. The Cahill Creek pluton separates the highly deformed ophiolitic Apex Mountain Group to the southeast from the less deformed Upper Triassic rocks further to the west. If the potassium-argon age dates from the Hedley and Similkameen intrusions represent intrusive ages, the Apex Mountain Group and Upper Triassic rocks in the Hedley district were probably juxtaposed after the emplacement of the Hedley diorites and before the intrusion of the Cahill Creek pluton. It is possible that the Cahill Creek pluton was intruded along the suture zone that originally separated these two contrasting crustal units.

MINERALOGICAL ZONING ASSOCIATED WITH SKARN ALTERATION IN THE HEDLEY DISTRICT

A consistent concentric zoning of gangue mineralogy is noted at many skarn-altered outcrops throughout the district (Figure 2-10-5); it resembles some of the classical skarn-related mineral zoning patterns described at other contact metasomatic deposits in the Canadian Cordillera (Dick, 1980; Dick and Hodgson, 1982). To date these zones have only been recognized on the outcrop scale, but preliminary field evidence suggests that similar, larger scale alteration envelopes are present around the French mine deposit (Plate 2-10-4). Although thin-section studies have identified various alteration assemblages throughout the Nickel Plate-Hedley Mascot deposit similar to the French mine, no consistent large-scale mineralogical zonation has yet been identified at the property. This probably reflects the immense size of the hydrothermal system responsible for the Nickel Plate-Hedley Mascot deposit which resulted in complex temporal and spatial overprinting of the alteration assemblages.

Exoskarn alteration in the district is best developed in the well-bedded, weakly tuffaceous and limy siltstones in the upper part of the Hedley sequence; on an outcrop scale, the more intense exoskarn alteration often selectively follows the narrow, impure calcareous beds. Ideally, passage from the inner, intensely altered and carbonate-rich exoskarn core to the outer, unaltered country rock is marked by up to five concentric zones of alteration (Figure 2-10-5). These zones vary from a few millimetres to tens of metres in thickness, but in areas of weak alteration the inner zones may be absent, and only one or two of the outer alteration zones developed.



D
INTRUSION OF
HEDLEY DIORITES UP
BASEMENT FRACTURES
WEST
EAST
C
AIRFALLS OF ASHTUFF
SEA LEVEL
CURRENTS
(UNIT A)
WHISTLE CREEK SEQUENCE
CONTINUING SUBSIDENCE
B
SEA LEVEL
COPPERFIELD
CONGLOMERATE
CURRENTS
COLLAPSE OF BASIN
A
SEA LEVEL
LIMESTONE REEFS
CURRENTS
HEDLEY SEQUENCE
BASEMENT

Figure 2-10-4. Postulated geological history of the Hedley area.

A — Upper Triassic (Carnian-Norian): Deposition of the Hedley sequence down a westerly inclined, basement-controlled basin margin. Shallow marine facies in the east, deeper water facies in the west.

B — Upper Triassic: Earth movements due to collapse of basin leads to the formation of the Copperfield conglomerate as a widespread gravity slide deposit.

C — Upper Triassic: Airfalls of andesitic ash tuffs result in the deposition of Unit A of the Whistle Creek sequence.

D — Mid-Jurassic: Reactivation of the basement flexure is accompanied by melting in the basement. These melts move upwards into the deforming cover rocks, resulting in the dioritic Hedley intrusions.

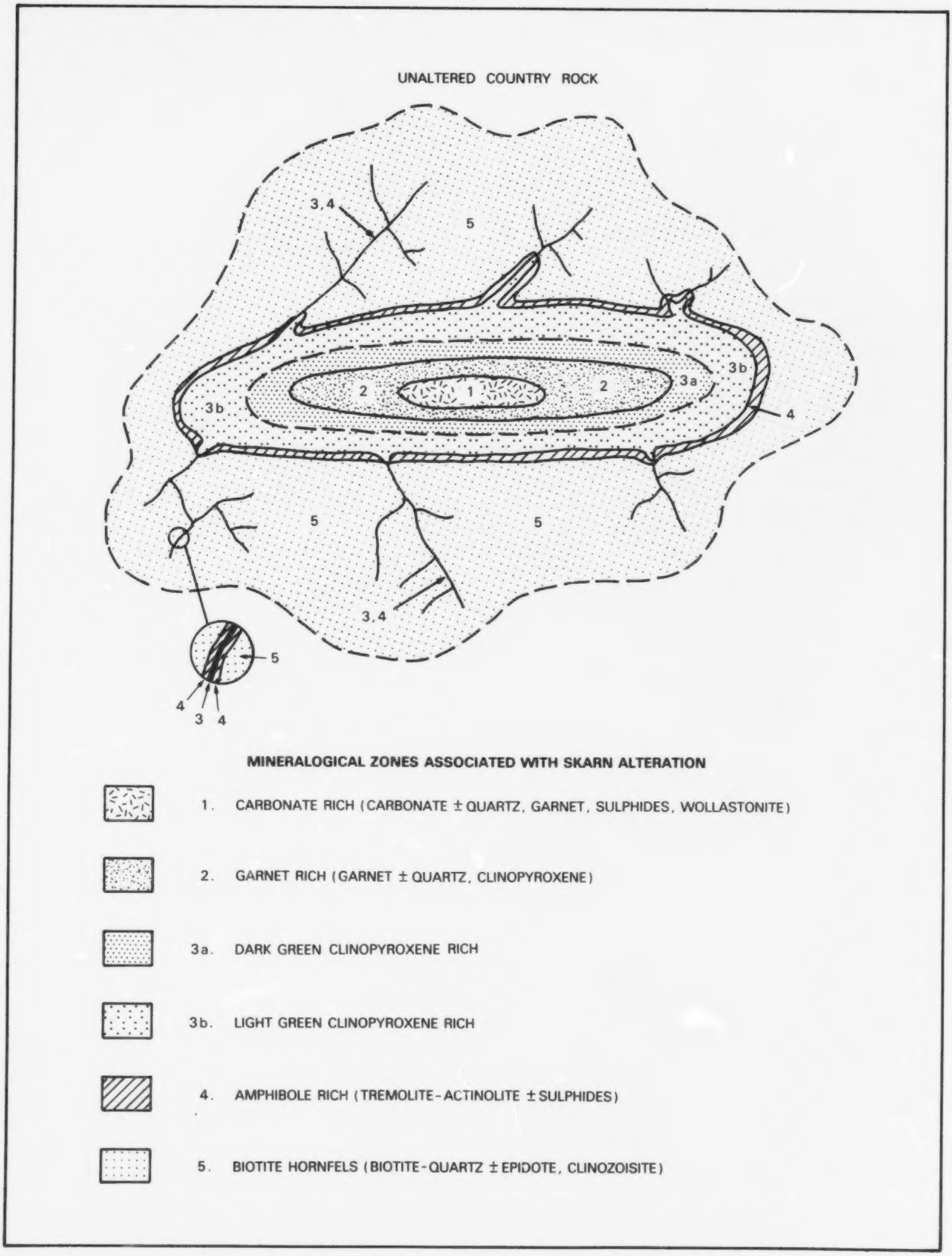

UNALTERED COUNTRY ROCK
3,4
5
3b
3a
2
1
2
3a
3b
4
5
5
3,4
5
4
3
4
MINERALOGICAL ZONES ASSOCIATED WITH SKARN ALTERATION
1. CARBONATE RICH (CARBONATE ± QUARTZ, GARNET, SULPHIDES, WOLLASTONITE)
2. GARNET RICH (GARNET ± QUARTZ, CLINOPYROXENE)
3a. DARK GREEN CLINOPYROXENE RICH
3b. LIGHT GREEN CLINOPYROXENE RICH
4. AMPHIBOLE RICH (TREMOLITE-ACTINOLITE ± SULPHIDES)
5. BIOTITE HORNFELS (BIOTITE-QUARTZ ± EPIDOTE, CLINOZOISITE)

Figure 2-10-5. Mineralogical zoning associated with skarn alteration in the Hedley gold camp.

Plate 2-10-4. Samples illustrating the various mineralogical zones associated with the skarn alteration at the French mine (*see* Figure 2-10-5).

A (Zone 5) — dark, massive biotite hornfels.
B (Zone 5) — biotite hornfels cut by thin veinlets of green clinopyroxene and minor amphibole.
C (Zone 3) — massive, light to dark green clinopyroxene with minor amphibole.
D (Zone 2) — massive, dark brown coarse-grained garnetite with minor clinopyroxene.
E (Zone 1) — "Pinto Formation" — intensely skarn-altered limestone conglomerate comprising white, coarsely crystalline marble clasts within a dark brown garnetite matrix.

The innermost core (Zone 1, Figure 2-10-5) generally lies adjacent to a carbonate-rich bed; it comprises coarse crystalline carbonate intergrown with minor amounts of coarse brown garnet, quartz and some sulphides and may also contain wollastonite and some rare axinite. Zone 2 is characteristically pinkish brown in colour and garnet rich (Plate 2-10-4). It contains both massive garnetite and isolated clusters of euhedral, coarse brown garnet intergrown with lesser amounts of clinopyroxene, quartz and sporadic sulphides. Rare scapolite may also be present. In thin section the euhedral garnets (possibly andradite) display sector twinning, some growth zonation and are distinctly birefringent (low order grey coloured) under crossed polars.

Zone 3 is green coloured and clinopyroxene rich (Plate 2-10-4). It contains abundant fine to coarse-grained clinopyroxene crystals intergrown with variable amounts of quartz. Scattered garnet may be present, but in thin section garnets are seen to be partially altered to clinozoisite while some pyroxenes are replacing earlier amphibole crystals. In some outcrops, this zone is separable into an inner dark green, probably iron-rich diopsidic subzone and an outer lighter green, probably iron-poor diopsidic subzone (Subzones 3A and 3B respectively, Figure 2-10-5).

Zone 4 is generally no more than a few centimetres thick, and may even be absent (Figure 2-10-5). It is typically dark green and characterized by abundant tremolite-actinolite, with sporadic sulphides. In thin section the amphibole is seen to locally replace and pseudomorph earlier biotite.

The outermost alteration zone (Zone 5, Figure 2-10-5) is variable in thickness and may have an irregular, diffuse contact with the unaltered country rock. This biotite-hornfels zone is characteristically dark brown coloured, siliceous, massive and fine grained (Plate 2-10-4). In thin section it is seen to comprise an intimate intergrowth of very small, decussate biotite and quartz crystals with minor epidote, clinozoisite and sulphides. The outermost biotite hornfels zone is commonly cut by a network of thin, light green-coloured veinlets of diopside and minor amphibole that represent Zones 3 and 4-type alteration (Figure 2-10-5). These pyroxene-rich veinlets can be irregular, but in many outcrops they show a preferential orientation following pre-existing microfractures (Plate 2-10-4). In areas of poor exposure this distinctive diopsidic veining is a useful indicator of nearby skarn alteration and possible mineralization, and consequently its presence could indicate areas worthwhile for prospecting.

DESCRIPTIONS OF SOME GOLD PROPERTIES

The geology, mineralization and alteration at the **Nickel Plate and Hedley Mascot mines** have been documented by Camsell (1910), Warren and Cummings (1936), Billingsley and Hume (1941), Dolmage and Brown (1945), Lee (1951) and more recently by Simpson and Ray (1986). The skarn-related mineralization at the property is stratabound and has selectively followed several favourable sedimentary horizons within a well-bedded succession of calcareous and tuffaceous siltstones and limestones in the upper part of the Hedley sequence (Figure 2-10-2). This gently dipping succession was intruded and hornfelsed by swarms of flat-lying diorite sills and some vertical dykes; both the intrusions and adjacent sediments were subsequently overprinted by skarn alteration. The gold-bearing sulphide horizons tend to be found near the outer margins of the exoskarn, close to the contact between skarn-altered thin-bedded silty or tuffaceous sediments and altered carbonates and marbles. Most mineralized zones occur as semi-conformable, lenticular bodies that are structurally controlled along either fold axes, fractures developed parallel to sill margins or at the intersection of diorite sills and dykes (Billingsley and Hume, 1941). On a smaller scale there is a lithological control to the mineralization which is often preferentially concentrated along certain favourable skarn-altered sedimentary beds. In some parts of the deposit irregular pods of gold-bearing massive sulphide ore are also developed; these contain abundant pyrite, pyrrhotite, arsenopyrite and chalcopyrite. Gold in the deposit occurs in native form as minute grains associated with arsenopyrite, gersdorffite and hedleyite (Bi_7Te_3), and as electrum associated with late-stage intergrowths of chalcopyrite, pyrrhotite, magnetite and sphalerite (Table 2-10-2).

The geology of the **Canty mine** area is not well known, partly due to very poor exposure. Rice (1947) briefly describes gold-arsenopyrite-rich mineralization in a faulted and folded zone of skarn-altered sedimentary rocks similar to those at the Nickel Plate mine. Rice (1947) notes the presence of a 120 to 130-metre-wide "granitic" dyke; recent examination of drill core abandoned on the property indicates that skarn-altered Hedley diorite intrusions are also present. This mapping project showed that the area surrounding the Canty mine is underlain mostly by andesitic ash and lapilli tuffs belonging to the lower portion of the Whistle Creek sequence (Unit A); locally these rocks are skarn-altered. The mine workings lie adjacent to the major, 20-kilometre-long, Cahill Creek fracture zone (Figure 2-10-1). This curvilinear fracture dips steeply southeast and underwent several episodes of movement; the earliest episode predates and partially controlled the intrusion of the Cahill Creek pluton (Figure 2-10-1). Fault movement resulted in downthrow to the south and southeast and a 4-kilometre left lateral displacement of the Copperfield conglomerate north of Ashnola Hill (Figure 2-10-1). In the Canty mine area, the Whistle Creek sequence tuffaceous rocks east of the Cahill Creek fracture zone are structurally overturned; they dip vertically to steeply west and young eastward. By contrast, the thin unit of tuffaceous rocks in the upthrown block immediately west of the fracture is structurally upright, gently dipping and are thought to overlie Hedley sequence sediments (Figure 2-10-3). It is believed that the Canty mine mineralization is hosted by an upthrown, fault-bounded slice of Hedley sequence sediments within the Cahill Creek fracture zone. Exploration in the vicinity should therefore be concentrated along extensions of this zone, and on drilling the favourable Hedley sequence sediments that lie at shallow depth west of the fracture (Figure 2-10-3).

The **French (Oregon) mine** area (Figure 2-10-1) is underlain by faulted and folded andesitic ash and lapilli tuffs, conglomerates and some limestones which are intruded by dioritic rocks of the Hedley intrusions; these all form part of an intensely hornfelsed roof pendant within the Cahill Creek pluton. The auriferous orebodies contain arsenopyrite, bornite and chalcopyrite (Table 2-10-2), and are mainly hosted by skarn-altered limy sediments and a distinctive conglomerate known locally as the "Pinto Formation" (Plate 2-10-4). This coarse conglomerate resembles the Copperfield conglomerate but contains more chert and siltstone clasts. The skarn mineralogy at the mine includes clinopyroxene, garnet, axinite and wollastonite (Table 2-10-2). In areas of more intense alteration the conglomerate consists of angular to rounded clasts of coarse white marble, set in a brown garnetite matrix (Plate 2-10-4).

The **Peggy (Hedley Amalgamated)** property lies close to the intrusive contact between a major dioritic Hedley intrusion, the Stemwinder pluton, and steeply dipping calcareous siltstones and thin limy beds of the Hedley sequence. The sediments are intruded by several altered diorite sills. The skarn-related mineralization appears to be both lithologically and structurally controlled and has been affected by either syn or post-mineralization faulting that resulted in the growth of botryoidal pyrite and pyrrhotite. Sporadically high gold values are associated with massive pyrite-arsenopyrite, containing traces of sphalerite and chalcopyrite (Table 2-10-2).

Banbury Gold Mines Ltd. (Figure 2-10-1) is currently working ground that includes the former Maple Leaf and Pine Knot properties. Geological data gathered during this mapping project have been supplemented considerably by informative discussions with M.R. Sanford of Banbury Gold Mines Ltd. The northerly striking, steeply dipping sedimentary and tuffaceous rocks on the property are intruded by two elongate, easterly trending diorite stocks belonging to the Hedley intrusions; they extend over a strike length of 1.3 kilometres and exceed 300 metres in width. The stocks intrude the Upper Triassic succession, crosscutting calcareous siltstones, argillites and thin limestones of the Hedley sequence in the east, a

TABLE 2-10-2
MINERALOGY OF THE GOLD DEPOSITS, HEDLEY GOLD CAMP

Skarn-related Mineralization (S-type)

Nickel Plate-Hedley Mascot mines — Electrum, arsenopyrite, pyrite, pyrrhotite, sphalerite, chalcopyrite, marcasite, galena, molybdenite, magnetite, titanite, bismuth tellurides (hedleyite, tetradymite), cobaltite, erythrite, platinum (as the arsenide sperrylite collected off the stamp mills), clinopyroxene, garnet, calcite, axinite, wollastonite, scapolite, apatite, clinozoisite, epidote, biotite, tremolite-actinolite and quartz.

French mine — Arsenopyrite, pyrite, chalcopyrite, bornite, pyrrhotite, clinopyroxene, garnet, calcite, axinite, wollastonite, clinozoisite, epidote, biotite, tremolite-actinolite and quartz. Cobalt bloom seen on weathered outcrops, and anomalous tungsten values reported.

Canty mine — Arsenopyrite, pyrite, chalcopyrite, pyrrhotite, clinopyroxene, calcite, garnet, epidote and quartz.

Good Hope mine — Arsenopyrite, pyrite, chalcopyrite, pyrrhotite, native bismuth, molybdenite, hedleyite, clinopyroxene, garnet, calcite, wollastonite, biotite, epidote and quartz.

Peggy (Heldey Amalgamated) — Arsenopyrite, pyrrhotite, pyrite, chalcopyrite, sphalerite, clinopyroxene, calcite, garnet, epidote and quartz.

Vein-related Mineralization (V-type)

Banbury Gold mine (Maple Leaf, Pine Knot) — Arsenopyrite, pyrite, chalcopyrite, sphalerite, galena, native gold, quartz and calcite.

Gold Hill — Pyrite, arsenopyrite, sphalerite, galena, chalcopyrite, quartz and calcite.

200-metre-thick section of the Copperfield conglomerate in the centre, and andesitic tuffs (Unit A) of the Whistle Creek sequence in the west. Both stocks comprise two rock types, a leucocratic quartz diorite suite containing 3 to 6 per cent hornblende ± biotite to the north and a highly mafic diorite-gabbro suite characterized by 25 to 50 per cent hornblende in the south. The stocks have irregular intrusive contacts that interfinger with the bedded country rocks, and are surrounded by a hornfelsic aureole. Both the stocks and aureole are cut by several irregular, northerly trending fracture zones that are filled by steep and shallow-dipping quartz ± carbonate vein systems; these include the Maple Leaf and Pine Knot veins. Individual veins are reported to be up to 3 metres wide and exceed 100 metres in length; they contain mainly glassy to white to pale pink-coloured, strained quartz with lesser amounts of coarse calcite, sporadic visible gold, arsenopyrite, pyrrhotite, pyrite, sphalerite and chalcopyrite (Table 2-10-2). Locally they are sheared, vuggy and contain angular brecciated clasts of chloritized, silicified country rock. Some veins have sheared or faulted margins and locally the contacts are marked by thin halos of very fine sericite. Sheared quartz veins that crosscut the hornfelsic metamorphic aureole are locally enveloped by a 1-metre-wide zone of "Zebra rock" comprising thin parallel calcite veins between 2 and 6 millimetres thick, spaced regularly 1 to 2 centimetres apart. Locally, the leucocratic diorite contains pockets of intense skarn alteration marked by coarse garnet and clinopyroxene. The quartz veins crosscut and postdate this skarn alteration. The margins of some veins are intruded by late, narrow andesitic dykes that carry disseminated pyrite and pyrrhotite but no gold.

The **Gold Hill** mineralization (Figure 2-10-1), like that at the Banbury Gold Mines property, is hosted by a carbonate ± quartz vein that cuts andesitic ash and lapilli tuffs and some tuffaceous sediments in the lowest stratigraphic portion of the Whistle Creek sequence (Unit A, Figures 2-10-1 and 2-10-2). The tuffaceous rocks are intruded by dykes and sills of both fine-grained and coarse hornblende porphyritic diorite of the Hedley intrusive suite; these intrusions locally carry disseminated pyrite and arsenopyrite. Some tuff beds adjacent to one porphyritic diorite body are hornfelsed and sporadically overprinted with early calcite-diopside-pyrite-chalcopyrite skarn alteration. Later faulting, along both the intrusive margins and within the diorite body, controlled a 60-metre-long, northwest-trending, irregular carbonate vein that reaches 15 metres in outcrop width. On surface this vein comprises coarse, crystalline white to pale buff carbonate, together with minor quartz and some disseminated pyrite cubes. However spoil dumps from short adits driven on the vein contain abundant vuggy quartz vein material similar in appearance to the Maple Leaf and Pine Knot veins. This quartz-rich material contains massive blebs of coarse pyrite with traces of arsenopyrite, chalcopyrite, black sphalerite and galena (Table 2-10-2). Locally the carbonate vein margins are densely packed with elongate, interlocking, sharply angular brecciated fragments of hornfelsed and skarn-altered wallrock up to 15 centimetres long. These clasts are rimmed with two generations of carbonate growth, an early, brown-coloured, possibly ankeritic carbonate, and a later phase of white crystalline calcite that was apparently coeval with the injection of the main carbonate-quartz vein. The sequence of events at the Gold Hill property was apparently as follows: (1) intrusion of the diorite body and biotite hornfelsing of the country rock, (2) weak skarn alteration with some sulphides, (3) fault brecciation, (4) minor ankerite injection, and (5) injection of the carbonate ± quartz ± sulphide vein with hydrostatic brecciation.

AN OVERVIEW OF THE GOLD MINERALIZATION IN THE DISTRICT

The location of the more significant gold-bearing properties in the district is shown in Figure 2-10-1 and precious metal production from the mines is summarized in Table 2-10-1. All of the gold occurrences and deposits shown in the figure are spatially associated with dioritic bodies of the Hedley intrusions. These intrusions vary in size from the relatively narrow sills and dykes at the Nickel Plate and Hedley Mascot mines to the larger stocks at the Banbury and Peggy properties. The gold mineralization can be broadly separated into skarn-related (S) and vein-related (V) types. The S-type is the most widespread and economically important; it is characterized by the gold being intimately associated with variable quantities of sulphide-bearing garnet-pyroxene-carbonate exoskarn alteration (Table 2-10-2). S-type mineralization is found at the Nickel Plate, Hedley Mascot, Good Hope, Canty, French and Peggy properties (Table 2-10-1). The V-type mineralization is seen only at the Banbury and Gold Hill properties. It is characterized by gold and sulphides hosted in higher level, fracture-filled quartz-carbonate vein systems (Table 2-10-2). It is noteworthy however, that pre-vein skarn alteration of the country rock is seen immediately adjacent to some veins on these properties. The S and V-types of mineralization are believed to be related and essentially coeval. Their differences probably reflect contrasting depths of formation; the S-type originates from deeper level contact metasomatism, while the V-type represents shallower hydrothermal systems that were channeled along tension fractures.

The volume of S-type alteration developed in different parts of the district varies dramatically in scale from that produced by the huge, complex hydrothermal system responsible for the Nickel Plate-Hedley Mascot orebodies, down to smaller gold-bearing systems that gave rise to the narrow, discontinuous zones of alteration and mineralization at the Peggy property. Barren S-type alteration and its associated Hedley intrusions are extremely common and widespread, but economically auriferous skarns are very rare. Even at the Nickel Plate-Hedley Mascot mines, where the hydrothermal system produced a broad zone of skarn-related alteration up to 300 metres thick and several kilometres in discontinuous strike length, the auriferous horizons are volumetrically minute compared to the overall size of the alteration zone. The diorite intrusions at the S-type properties, even when extensively altered to endoskarn, seldom carry economic gold, although some contain anomalous gold values in the parts per billion range. In the more intensely skarn-altered diorites, the original hornblende phenocrysts are totally replaced by pyroxene and most of the igneous textures destroyed. However, their original intrusive nature can often be determined by the preservation of the distinctly zoned, coarse igneous plagioclase phenocrysts which were highly resistant to endoskarn alteration.

Economic gold values at all the S-type properties are almost wholly confined to the exoskarn; gold tends to be associated with sulphides (particularly arsenopyrite), and is not so common in the more sulphide-poor, pristine garnet-pyroxene-carbonate skarn. However, at present there is no totally reliable visual method of distinguishing barren skarn from ore. At the Nickel Plate property, for example, some arsenopyrite-rich zones are virtually barren, while in rare instances, the sulphide-lean zones are auriferous. Preliminary thin-section studies at the Nickel Plate and French mines suggest that gold is erratically associated with areas of retrograde alteration marked by late tremolite-actinolite growth.

There is an overall stratigraphic and lithological control to the gold mineralization in the camp. Most of the extensive skarn development and economic mineralization is hosted by the shallow marine facies sedimentary rocks of the Hedley sequence, particularly the 100 to 400-metre-thick limestone-rich sedimentary section that immediately underlies the Copperfield conglomerate (Figure 2-10-2). Skarn-altered conglomerate hosts the French mine mineralization (Plate 2-10-4), and the Nickel Plate-Hedley Mascot ore zones are hosted by calcareous and tuffaceous sediments that underlie stratigraphically the Copperfield conglomerate.

CONCLUSIONS

The Hedley district is mostly underlain by an Upper Triassic Nicola Group succession that is divisible into a younger, predominantly volcaniclastic Whistle Creek sequence and an older, predominantly sedimentary Hedley sequence. These are separated by a limestone-boulder-bearing olistostrome, the Copperfield conglomerate, which forms a distinctive stratigraphic marker horizon throughout the district. An east-west sedimentary facies change is recognized in the Hedley sequence reflecting a westerly inclined basin margin. Deeper water marine sediments with only minor, thin limestone beds were laid down by westerly directed paleocurrents in the west, while shallower water siltstones, conglomerates and thick reefal limestones were deposited in the east. The change from shallow to deep water facies rocks coincides approximately with the late, northerly trending Bradshaw fault (Figure 2-10-1), and the basin margin was probably controlled by an ancient structural flexure in the basement rocks believed to underlie the Triassic cover (Figure 2-10-4A).

Reactivation of the basement flexure during the Middle Jurassic led to the melting responsible for the dioritic Hedley intrusions. These melts moved upwards into the cover rocks and are now concentrated along a northerly trending, basement-controlled zone that marks the change from shallow to deep water facies in the Hedley sequence (Figure 2-10-4D).

Subsequently, the moderately deformed Whistle Creek and Hedley sequences were juxtaposed against the highly deformed, ophiolitic Apex Mountain Group further to the southeast. The contact between the Nicola and Apex Mountain Groups probably represents a fundamental fracture or suture zone that was later intruded and sealed by the Late Jurassic, granodioritic Cahill Creek pluton.

The lowest portion of the Whistle Creek sequence (Unit A) comprises andesitic tuffs that are believed to be stratigraphically equivalent to the Nicola Group rocks further west. However the upper portions of the sequence (Units B and C) include fresh, quartz-bearing dacitic tuffs that may belong either to the Upper Triassic Nicola Group or to the Cretaceous Kingsvale or Spences Bridge Groups. If a Cretaceous age was proved for these rocks, it would indicate the existence of a major unconformity within the Whistle Creek sequence.

The Early Jurassic Hedley intrusions are spatially associated with two contrasting, but essentially coeval types of gold mineralization. The most widespread and economically significant (S-type) is associated with deeper level contact metasomatic diopside-garnet-carbonate skarn alteration assemblages, while the V-type is poorly developed, less economically important and is associated with higher level, tension-fracture-filled quartz-carbonate vein systems. The volume of S-type skarn alteration developed throughout the district varies in scale from outcrop size up to the huge alteration zone surrounding the Nickel Plate-Hedley Mascot orebodies. Barren S-type skarn alteration and its associated Hedley intrusions are extremely widespread in the district but auriferous skarns are very rare. Economic gold values are almost wholly confined to the exoskarn, but there is no totally reliable visual method of distinguishing barren skarn from ore. A small-scale, consistent, concentric zoning of gangue mineralogy is present at many skarn-altered outcrops (Figure 2-10-5). Preliminary studies suggest that similar, larger scale mineralogical zoning patterns may surround some of the S-type gold deposits (Plate 2-10-4). If proven, this could provide an additional exploration tool for outlining S-type mineralization.

The main controls of S-type mineralization in the camp are:

(1) The presence of numerous Hedley intrusions, particularly swarms of sills and dykes which are considered more favourable for contact metasomatism than larger stocks.

(2) The presence of the limestone-rich, shallow marine facies sedimentary rocks of the Hedley sequence. There is an overall stratigraphic control to the skarn development and economic mineralization in the camp; the 100 to 400-metre-thick succession that immediately underlies the Copperfield conglomerate is the preferred host for mineralization (Figure 2-10-2).

(3) The presence of local controlling structures such as sill-dyke intersections, fractured sill margins and fold hinges, as noted by Billingsley and Hume (1941) at the Nickel Plate mine.

These controls suggest that:

(1) Outlining possible northern and southern regional extensions of the Upper Triassic basin margin and its associated Hedley intrusive swarms outside the Hedley camp could help locate other areas containing Hedley-type gold mineralization.

(2) Since most of the economic mineralization in the camp is stratigraphically and lithologically controlled within the upper 400-metre-thick section of the Hedley sequence shallow marine facies rocks, and the overlying Copperfield conglomerate, areas containing skarn alteration in this stratigraphic position warrant more detailed exploration.

Some extensive areas with these favourable features were noted during this program. They include:

(1) The area east of the Bradshaw fault, south of Lookout Mountain and north and northwest of the Nickel Plate mine (Figure 2-10-1). Widespread skarn alteration with some arsenopyrite is found over a broad area within a thick section in the upper part of the Hedley sequence. This section could represent a downfaulted, northerly extension of the Nickel Plate mine mineralized horizons.

(2) The Copperfield conglomerate and reefal limestone-bearing Hedley sequence rocks east of Ashnola Hill (Figure 2-10-1) are intruded by swarms of dioritic sills and extensively skarn altered. A broad, northerly trending zone of skarn alteration with sporadic arsenopyrite is seen over a strike length of 3 kilometres.

Finally, although the V-type mineralization has been economically disappointing in the camp (Table 2-10-1), these higher level veins probably result from the venting of silica and carbonate-rich fluids produced during deeper level skarn alteration. Consequently the V-type systems could pass downward into larger, gold-rich skarn systems.

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GEOCHRONOLOGY OF THE STEWART MINING CAMP (104B/1)

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INTRODUCTION

This report presents a revised interpretation of the geologic history of the Stewart area based on new potassium-argon dates and all previously published geochronological data from the district. The isotopic dates from the Stewart mining camp are erratically distributed over a 186-million-year (Ma) range from Triassic to Oligocene (Table 2-11-1). Dates from samples of the same rock unit vary significantly. However, when field observations are combined with the concept of the "metamorphic veil" (Armstrong, 1966) and with closure temperatures for argon loss in minerals, a simple explanation emerges for the distribution of dates listed in Table 2-11-1.

In 1986, potassium-argon dating was completed for a suite of rock samples from the alteration envelopes surrounding three mineral deposits in the area. Other isotopic dating near Stewart has been reported by Smith (1977) and by Alldrick, Mortensen and Armstrong (1986). Additional geochronological studies in the Stewart district are in progress by R.G. Anderson at the Geological Survey of Canada and by D.A. Brown at The University of British Columbia. Potassium-argon dates have also been determined in a similar geologic setting in the nearby Alice Arm area by N.C. Carter (1981) and at the Dolly Varden mine by B.D. Devlin (Devlin and Godwin, 1986).

Detailed descriptions of rock types, their distribution, and their field relationships in the Stewart camp are provided in Alldrick (1985) and are simplified here in Figure 2-11-1.

ANALYTICAL METHODS

Potassium-argon analyses were completed on whole-rock samples and on hornblende, biotite and potassium feldspar mineral separates. All samples were sieved to -30 to -60 mesh.

TABLE 2-11-1.
DATES FROM THE STEWART MINING CAMP IN CHRONOLOGICAL ORDER

Apparent Age (Ma)		Rock Unit	Rock Type	Mineral	Analytical Method
†211	6	tcg	Hornblende granodiorite stock	Hornblende	K/Ar
†202	6	tcg	Hornblende granodiorite stock	Hornblende	K/Ar
195.0	2.0	tcg	Hornblende granodiorite stock	Zircon	U/Pb
194.8	2.0	tcg	Premier Porphyry dyke	Zircon	U/Pb
192.8	2.0	tcg	Hornblende granodiorite stock	Zircon	U/Pb
189.2	2.2	tcg	Hornblende granodiorite dyke	Zircon	U/Pb
186	6	tcg	Hornblende lamprophyre dyke	Hornblende	K/Ar
†130	3	tcg	Hornblende granodiorite stock	Biotite	K/Ar
†108	3	tcg	Hornblende granodiorite stock	Biotite	K/Ar
101	3	le	Sericite-flooded andesite tuff	Whole Rock	K/Ar
89.0	3.0	tcg	Sericite-flooded Premier Porphyry	Whole Rock	K/Ar
87.2	3.0	tcg	Sericite-flooded Premier Porphyry	Whole Rock	K/Ar
81.9	2.8	vein	K-feldspar in quartz vein	K-feldspar	K/Ar
78.5	2.8	le	Sericite-flooded andesite tuff	Whole Rock	K/Ar
62.9	2.3	tcg	K-feldspar-flooded Premier Porphyry	Whole Rock	K/Ar
54.8	1.3	hqm	Biotite granodiorite dyke	Zircon	U/Pb
†53.8	2.0	hqm	Biotite granodiorite stock	Hornblende	K/Ar
†52.2	4.0	hqm	Biotite granodiorite stock	Biotite	K/Ar
†51.6	2.0	hqm	Biotite granodiorite stock	Hornblende	K/Ar
†50.5	2.0	hqm	Biotite granodiorite stock	Biotite	K/Ar
†50.4	2.0	hqm	Biotite granodiorite stock	Biotite	K/Ar
†49.9	2.0	hqm	Biotite granodiorite stock	Hornblende	K/Ar
48.4	1.7	hqm	Biotite granodiorite stock	Biotite	K/Ar
†47.3	1.0	hqm	Biotite granodiorite stock	Biotite	K/Ar
45.2	1.6	tcg	Hornblende granodiorite stock	Biotite	K/Ar
†44.8	1.5	hqm	Biotite granodiorite stock	Biotite	K/Ar
42.7	1.5	le	Sericite-flooded andesite tuff	Whole Rock	K/Ar
25.2	1.0	dyke	biotite lamprophyre dyke	Biotite	K/Ar

† Dates from Smith (1977), recalculated with IUGS decay constants.

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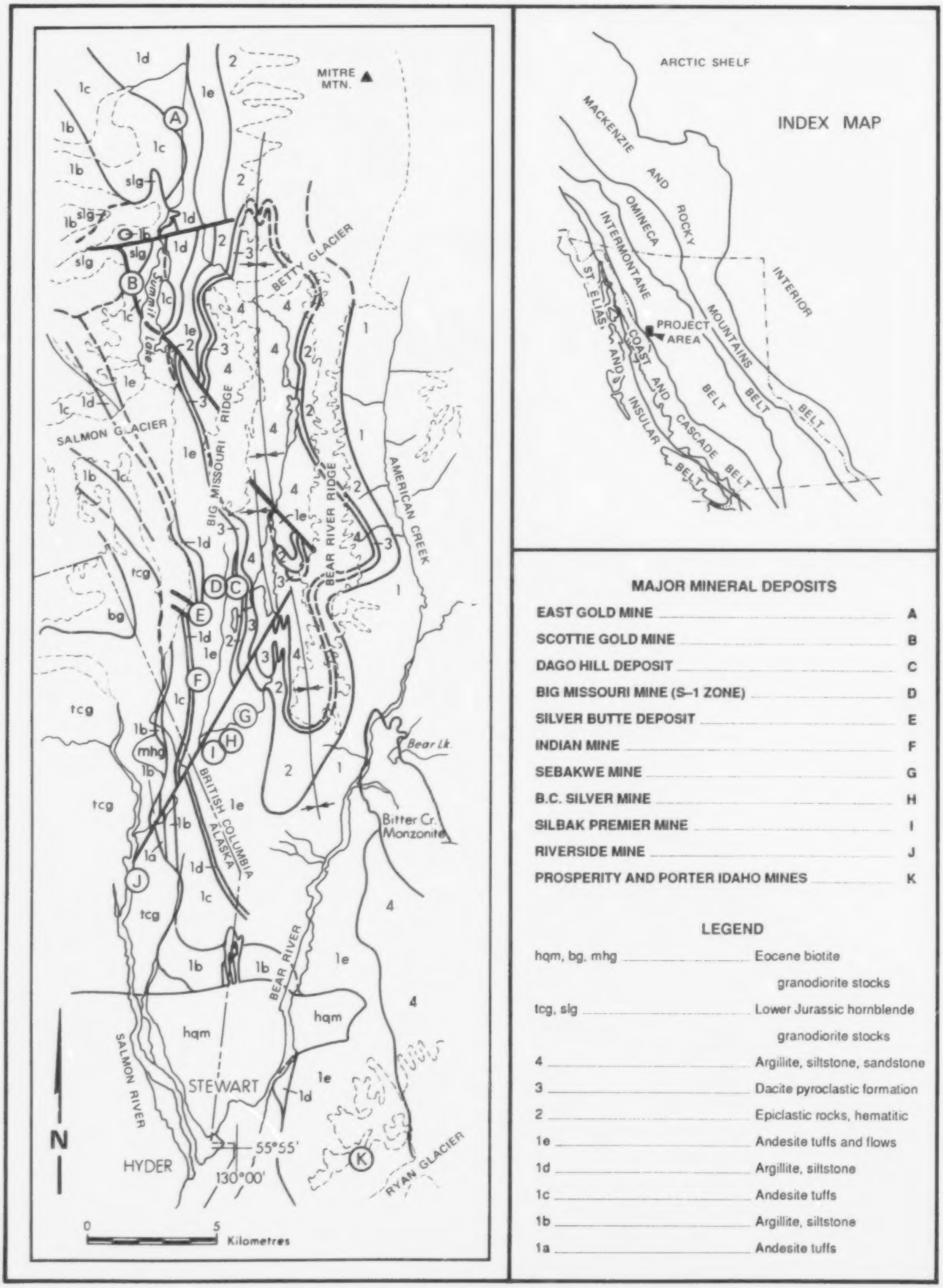
* Presently with the Geological Survey of Canada.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.


MITRE MTN.
BETTY GLACIER
SALMON GLACIER
Summit Lake
BIG MISSOURI RIDGE
BEAR RIVER RIDGE
AMERICAN CREEK
Bear Lk.
Bitter Cr. Monzonite
BRITISH COLUMBIA
ALASKA
BEAR RIVER
SALMON RIVER
STEWART
HYDER
55°55'
130°00'
RYAN GLACIER
N
0
5
Kilometres
INDEX MAP
ARCTIC SHELF
MACKENZIE AND ROCKY MOUNTAINS BELT
OMINECA BELT
INTERMONTANE BELT
COAST AND CASCADE BELT
ST. ELIAS AND INSULAR BELT
INTERIOR
PROJECT AREA

MAJOR MINERAL DEPOSITS

EAST GOLD MINE	A
SCOTTIE GOLD MINE	B
DAGO HILL DEPOSIT	C
BIG MISSOURI MINE (S–1 ZONE)	D
SILVER BUTTE DEPOSIT	E
INDIAN MINE	F
SEBAKWE MINE	G
B.C. SILVER MINE	H
SILBAK PREMIER MINE	I
RIVERSIDE MINE	J
PROSPERITY AND PORTER IDAHO MINES	K

LEGEND

hqm, bg, mhg	Eocene biotite granodiorite stocks
tcg, slg	Lower Jurassic hornblende granodiorite stocks
4	Argillite, siltstone, sandstone
3	Dacite pyroclastic formation
2	Epiclastic rocks, hematitic
1e	Andesite tuffs and flows
1d	Argillite, siltstone
1c	Andesite tuffs
1b	Argillite, siltstone
1a	Andesite tuffs

Figure 2-11-1. Geology and mineral deposits of the Stewart area (from Alldrick, 1985).

TABLE 2-11-2.
NEW POTASSIUM-ARGON DATES FROM THE STEWART CAMP

Sample No.	Location (Minfile No.)	Mineral or Concentrate	%K	^{40}Ar rad. 10^{-6} cc/gm	% $\frac{^{40}\text{Ar rad.}}{^{40}\text{Ar total}}$	$\frac{^{40}\text{Ar. rad.}}{^{40}\text{K}} \times 10^{-3}$	Apparent Age (Ma)
Premier G.H.[1] Lat. 56°03.1′ Long. 130°00.7′	Southeast rim of Silbak Premier gloryhole (MI 104B-54)	Whole rock, sericite flooded	6.38 ± 0.09 n = 3	22.624	93.1	5.301	89.0 ± 3.0
PM84-29-232′[1] Lat. 56°03.1′ Long. 130°00.7′	Core sample from Premier gloryhole area (MI 104B-54)	Whole rock, sericite flooded	4.92 ± 0.02 n = 3	17.079	95.2	5.189	87.2 ± 3.0
PM84-25-369′[1] Lat. 56°03.1′ Long. 130°00.7′	Core sample from Premier gloryhole area (MI 104B-54)	K-feldspar, from quartz vein	11.44 ± 0.03 n = 3	37.268	94.3	4.870	81.9 ± 2.8
81-58-25′[1] Lat. 56°06.4′ Long. 130°00.7′	Dago Hill zone, Big Missouri camp (MI 104B-45)	Whole rock, sericite flooded	4.13 ± 0.07 n = 3	16.681	89.8	6.038	101 ± 3
81-58-68′[1] Lat. 56°06.4′ Long. 130°00.7′	Dago Hill zone, Big Missouri camp (MI 104B-45)	Whole rock, sericite flooded	4.52 ± 0.03 n = 3	14.087	86.0	4.659	78.5 ± 2.8
IM-10[1] Lat. 56°04.6′ Long. 130°01.9′	Galena Cuts zone, Indian mine (MI 104B-31)	Whole rock, sericite flooded	5.68 ± 0.05 n = 5	9.542	87.4	2.511	42.7 ± 1.5
L-2[1] Lat. 56°14.8′ Long. 130°04.3′	Blueberry vein (MI 104B-133)	Hornblende, from lamprophyre dyke	0.847 ± 0.017 n = 5	6.433	90.9	11.359	186 ± 6
A84-1-8[1] Lat. 56°02.0′ Long. 129°55.0′	Roadside quarry on Stewart Hwy.	Biotite, Bitter Creek granodiorite	6.75 ± 0.06 n = 5	12.878	79.7	2.852	48.4 ± 1.7
DB-84-25[2] Lat. 56°03.3′ Long. 130°00.5′	Trench 2190 at Premier gloryhole	Whole rock K-feldspar flooded	5.92 ± 0.05 n = 2	14.721	82.2	3.717	62.9 ± 2.3
B-383[2] Lat. 55°59.3′ Long. 130°03.8′	Roadcut 2.0 km south of Riverside mine	Biotite, Texas Creek granodiorite	4.17 ± 0.02 n = 2	7.416	84.4	2.659	45.2 ± 1.6
AT84-27-5[2] Lat. 56°04.4′ Long. 130°02.4′	Roadcut on east side of Indian Lake	Biotite, lamprophyre dyke	7.22 ± 0.01 n = 2	7.133	68.0	1.477	25.2 ± 1.0

[1] K analyses by P.F. Ralph and B. Bhagwanani, Ministry of Energy, Mines and Petroleum Resources; D. Alldrick samples.

[2] K analyses by K. Scott, The University of British Columbia; D. Brown samples.

All Ar analyses by J.E. Harakal, The University of British Columbia.

P.F. Ralph and B. Bhagwanani carried out sample preparation and potassium analysis at the laboratory of the British Columbia Ministry of Energy, Mines and Petroleum Resources. Following sample fusion with $LiBO_2$ at 1050°C, the glass beads were dissolved in 6 per cent HNO_3 with 3 millilitres of 50 per cent HF; a small amount of CsCl was added as a buffer. Potassium abundance was measured on a Perkin Elmer Model 107 single-beam atomic absorption spectrophotometer.

Argon analysis was completed at the Department of Geological Sciences, The University of British Columbia. Samples were fused using a Phillips radiofrequency induction heater and spiked with high purity argon-38. The gas mixture was purified by passing over titanium "getter" furnaces. Argon isotopic ratios were measured in an Associated Electrical Industries MS-10 mass spectrometer equipped with a Carey model 31 vibrating reed electrometer. Analyses of standards indicate potassium and argon accuracy better than 2 per cent. Estimated precision of the analyses is given in Table 2-11-2.

Zircons were separated from 20 to 40-kilogram rock samples using a standard Wilfley table, heavy liquids and magnetic separation techniques. They were sized using nylon mesh screens and hand picked to 100 per cent purity. Chemical dissolution and mass spectrometry follow the procedures of Krogh (1973). We use a mixed ^{208}Pb-^{235}U spike and measure lead and uranium on an automated Vacuum Generators Isomass 54R solid source mass spectrometer. Automation and data reduction are done with a dedicated Hewlett-Packard HP-85 computer. Errors associated with isotopic ratios and calculated ages are obtained by individually propagating all calibration and analytical uncertainties through the entire date calculation program and summing all the individual contributions to the total variance.

All the dates in this report have been calculated with the decay constants and atomic ratios recommended by the Subcommission on Geochronology of the International Union of Geological Sciences (Steiger and Jäger, 1977).

RESULTS

The results of these new potassium-argon analyses are listed in Table 2-11-2. Potassium-argon dates from Smith (1977) have been recalculated and are listed in Table 2-11-1. Uranium-lead dates reported in Alldrick, Mortensen and Armstrong (1986) are presented with analytical data in Table 2-11-3.

DISCUSSION

It was hoped that the new potassium-argon analyses would reveal the age of mineralization at the Silbak Premier mine (MI 104B-054), the Dago Hill deposit (MI 104B-045) near the Big Missouri mine, and the Indian mine (MI 104B-031). However, significantly different dates were obtained from two samples of altered wallrock from a single diamond-drill hole at the Dago Hill deposit. These results indicate that a simple interpretation of the dates, as direct measurements of the age of alteration and mineralization, cannot be valid. In addition, contrasting dates obtained by Smith (1977) for hornblende and biotite separates from samples of Texas Creek granodiorite suggest that there has been argon loss from at least some mineral phases in these rocks. A brief review of the vulnerability of minerals to argon loss follows.

Early experimental and geochronometric studies have shown that minerals will lose argon gas from their crystal lattices when heated to moderate temperatures over geologically short periods of time (reviewed in Armstrong, 1966; Dodson, 1973; York, 1984). The lowest temperature at which minerals rapidly lose argon has been termed the "threshold temperature" (Armstrong, 1966), "closure temperature" (Dodson, 1973), and "blocking temperature" (York, 1984). Closure temperature is largely dependent on grain size and mineral type. Parrish and Roddick (1984) have compiled closure temperatures for mineral phases and mineral groups (Table 2-11-4).

Armstrong (1966) argued that temperature increases during regional metamorphism would drive off argon from many minerals whose potassium-argon dates would then be reset to record only the time of the final cooling of the orogen. If the temperatures were high enough all potassium-argon dates relating to the pre and syn-metamorphic history of the rocks would be lost or degraded to younger values. This concept of a "metamorphic veil" is illustrated schematically for a high-grade region in Figure 2-11-2. In the case of high-grade regional metamorphism, all mineral groups would have their potassium-argon "clocks" reset because the temperature peak during metamorphism far exceeds the closure temperatures of all minerals.

Regional metamorphic grade in the Stewart area was at most lower greenschist facies based on the illite and chlorite mineralogy of both sedimentary and tuffaceous rocks, and the absence of regionally distributed garnet and biotite. Lower greenschist facies metamorphism indicates a thermal peak of 300°C to 350°C (Smith,

TABLE 2-11-3.
URANIUM-LEAD ZIRCON DATA[1] (from Alldrick, Mortensen and Armstrong, 1986)

Sample No.	Location [UTM]	Sample Properties	Weight (mg)	Concentration (ppm) U	Pb	Observed $^{206}Pb/^{204}Pb$	Atomic Ratios[3,4] $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Model Ages (Ma)[4] $^{206}Pb/^{238}U$	$^{207}Pb/^{235}U$	$^{207}Pb/^{206}Pb$	Concordia Age (Ma)[4]
A84-1	(130°05′55″W 56°14′00″N)	nm, 150-215μm	16.3	459	13.6	8840	0.03035±16	0.2092±11	0.04998±007	192.8±1.0	192.9±0.9	194.2± 3.3	192.8±2.0
	[09-432250E 6232320N]	m, <45μm	1.3	1908	55.6	8472	0.02952±16	0.2041±11	0.05014±009	187.5±1.0	188.6±0.9	201.4± 4.0	
		m, <45μm	1.5	887	26.2	6498	0.02962±16	0.2048±11	0.05015±013	188.2±1.0	189.2±0.9	202.0± 5.8	
A84-2	(130°03′18″W 56°05′28″N)	nm, >150μm	14.2	349	10.2	8109	0.02979±17	0.2049±11	0.04990±006	189.2±1.1	189.3±0.9	190.3± 2.8	189.2±2.2
	[09-434400E 6216475N]	m, <75μm	0.3	898	27.8	1278	0.03056±17	0.2101±73	0.04987±062	194.1±1.1	193.7±6.1	189.1±75.5	
A84-3	(130°03′18″W 56°05′28″N)	nm, >150μm	10.5	596	18.6	1838	0.03062±17	0.2113±15	0.05006±025	194.4±1.0	194.7±1.3	197.7±11.7	195.0±2.0
	[09-434400E 6216475N]	nm, >150μm, abd	4.3	510	15.6	6189	0.03072±16	0.2117±11	0.04999±009	195.0±1.0	195.0±0.9	194.4± 4.1	
		m, <45μ	1.3	1272	38.3	6639	0.03004±16	0.2078±11	0.05016±009	190.8±1.0	191.7±0.9	202.6± 4.1	
A84-5	(130°00′50″W 56°03′06″N)	nm, >150μm	5.3	343	10.84	1081	0.03020±16	0.2090±12	0.05018±017	191.8±1.0	192.7±1.0	203.5± 7.6	194.8±2.0
	[090436760E 6212240N]	nm, >150μm, abd	2.9	378	11.7	1864	0.03067±16	0.2120±13	0.05013±019	194.8±1.0	195.2±1.1	201.2± 8.9	
AT-34-3[2]	(130°01′22″W 56°03′02″N)	nm, >150μm	5.0	362.2	4.14	629	0.01064±06	0.0702±05	0.04789±002	68.2±0.4	68.9±0.5	93.7±10.1	54.8±1.3
	[09-436300E 6212130N]	m, <75μm	1.0	431.2	4.34	225	0.00853±12	0.0554±14	0.04713±093	54.8±0.8	54.8±1.3	55.6± 4.6	

[1] All analyses by J.K. Mortensen, Geological Survey of Canada, Ottawa.

[2] Data provided by R.G. Anderson, Geological Survey of Canada, Vancouver.

[3] The errors apply to the last digits of the atomic ratios.

[4] All errors shown are 1 "σ" errors, except for 2 "σ" errors in final column.

Isotopic composition of blank: 6/4:17.75, 7/4:15.57, 8/4:37.00.

Isotopic composition of common lead is based on the Stacey and Kramer (1975) model.

1981, page 91). From the closure temperatures listed in Table 2-11-4 only certain mineral groups should show argon loss during lower greenschist facies metamorphism. Figure 2-11-3 shows a schematic diagram which predicts the effects of lower greenschist facies temperatures on potassium-argon dates for a variety of minerals.

TABLE 2-11-4.
CLOSURE TEMPERATURES FOR ARGON LOSS IN MINERALS

Mineral	**Data from Parrish and Roddick (1984)**
Hornblende	530° ± 40°C
Muscovite	~350°C
Biotite	280° ± 40°C
K-feldspar	130 ± 15°C
Microcline	110°C

Note that although the closure temperature for coarse-grained igneous muscovite is estimated at 350°C, fine-grained hydrothermal "sericite" that is present in the Stewart samples will be some variety of muscovite, paragonite, hydromuscovite, illite or phengite, and may even be a mixed, layered aggregate of a few of these minerals (Deer *et al.*, 1963, pages 215-216). The closure temperature for sericite is not known, but the fine-grained, hydrous mineral aggregate would be particularly susceptible to water loss and argon diffusion during heating. Therefore the closure temperature for hydrothermal sericite is probably below 300°C and thus similar to biotite.

INTERPRETATION

All dates from Table 2-11-1 are displayed on Figure 2-11-4. Note that this figure includes uranium-lead dates from zircons which are estimated to have closure temperatures of >500°C and thus are not easily susceptible to thermal resetting at greenschist facies temperatures. As illustrated in Figures 2-11-2 and 2-11-3, the "date" of a mineral represents the last time the mineral cooled down through its closure temperature, whether the temperature drop resulted from original cooling of an igneous magma or from cooling after a metamorphic event.

The broad grey band on Figure 2-11-4 represents the interpreted regional thermal history for the Stewart mining camp. The black lines represent the interpreted thermal history of discrete igneous bodies such as dykes and stocks. The cooling curve after each thermal "peak" is drawn through the data points. The temperature rise of each thermal peak and details of any prior cool interval cannot be exactly reconstructed. For igneous bodies the temperature rise can be considered virtually instantaneous — a vertical line, but for the regional metamorphic event the temperature rise is hidden behind the metamorphic veil and must be strictly hypothetical — a dashed grey band.

The dates for two mineral groups, biotites from the Texas Creek granodiorite and sericite-rich rocks from the Silbak Premier, Dago Hill (Big Missouri) and Indian deposits, require further comment.

The biotite separates from the Texas Creek granodiorite are clearly reset since their potassium-argon dates do not match those for hornblende separates from the same samples (Table 2-11-1; Smith, 1977)). Also, the potassium-argon dates for the reset biotites differ by 22 million years even though the dates for the two hornblende separates lie within analytical error of each other. This is interpreted to be the result of only partial argon loss from the older biotite (sample 3S-008 of Smith, 1977). Partial argon loss occurs either when the thermal peak is short lived, such as country rock intruded by a narrow dyke, or when the thermal peak barely reaches

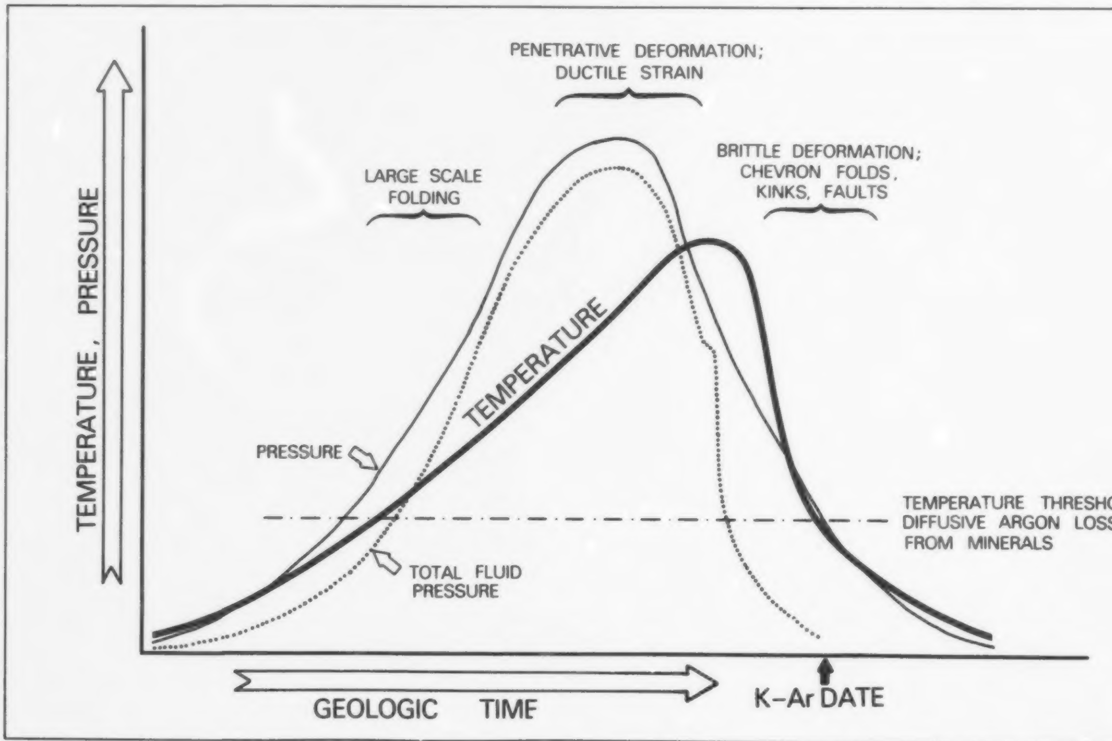


Figure 2-11-2. General relationships of temperature, pressure, deformation and argon loss from minerals in the metamorphic interior of an orogenic belt (from Armstrong, 1966).

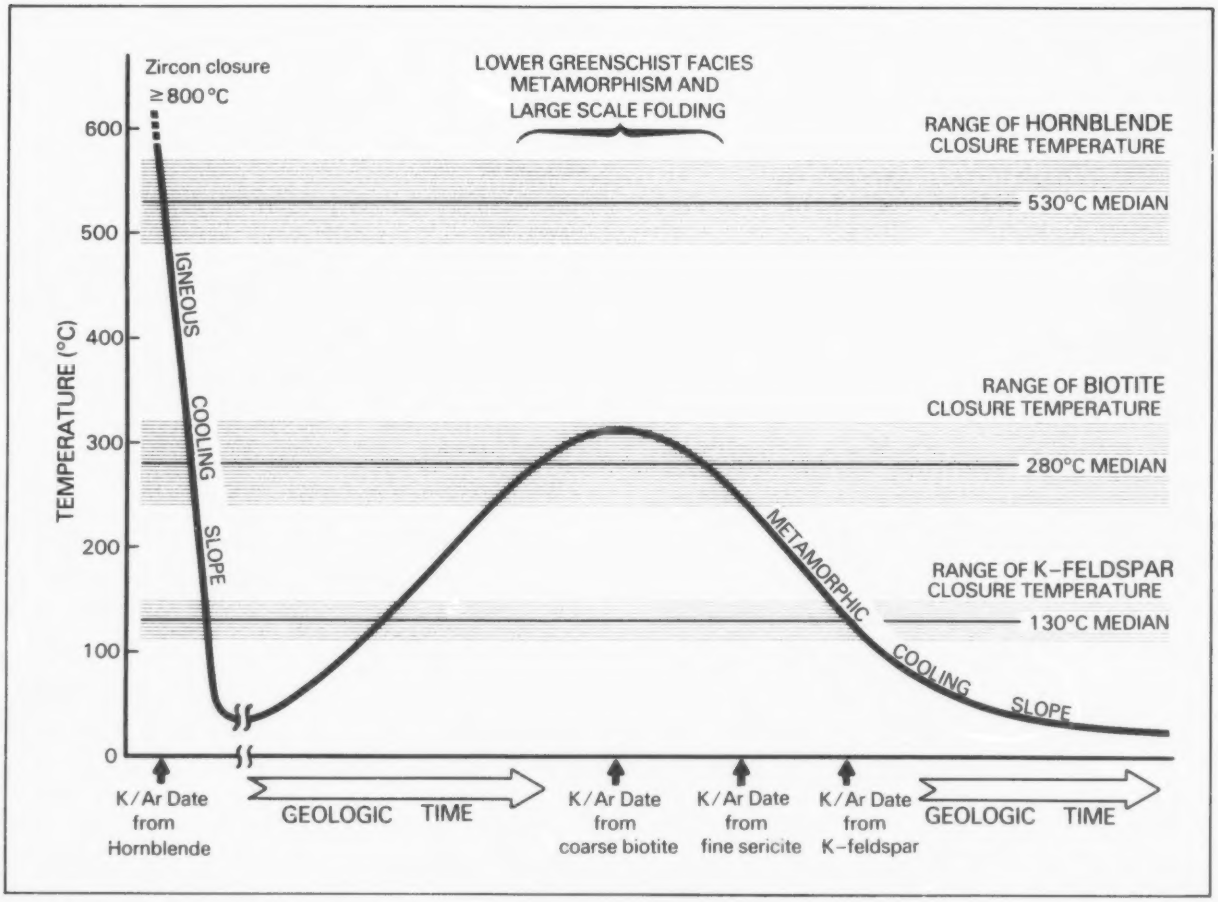


Figure 2-11-3. General relationships of temperature, deformation and argon loss for minerals dated in the Stewart mining camp.

a temperature equal to the closure temperature for the mineral. Coarse-grained igneous biotites are estimated in general to have closure temperatures of 240 to 320°C and, since the thermal peak of regional metamorphism was,probably not a short lived event, the temperatures during regional metamorphism are inferred to have reached but not exceeded 300°C. It is also possible that the two biotite separates had slightly different closure temperatures, or that the maximum temperature during regional metamorphism varied between the sample locations, which were 3 kilometres apart (Smith, 1977). A third biotite separate from the Texas Creek granodiorite, sample B-383 in Table 2-11-2, has been dated at 45.2 Ma. This sample was collected near the northern contact of the Hyder stock and the potassium-argon ratio of the biotite has been thermally reset by the Tertiary intrusion.

Two dates for sericite-rich altered dyke rock from the Silbak Premier mine, 87.2 and 89.0 Ma, fall within analytical error of each other and are considered the most representative values for thermally reset sericite dates. The potassium feldspar date from the Silbak Premier mine, 82 Ma, gives a reasonable additional control for the cooling curve after regional metamorphism.

The dates for two sericite-rich altered andesite samples from a single drill hole at Dago Hill are quite different, 78.5 Ma and 101 Ma. Thin section study of these two samples shows that the deeper core sample, which yields the younger date, is composed of sericite and carbonate-altered andesitic ash tuff (Plate 2-11-1). The shallower core sample is similarly altered andesitic crystal tuff containing large laths of hornblende that have been extensively altered to coarse sericite (Plate 2-11-2). The closure temperature for hornblende is well above the thermal peak reached during regional metamorphism (Figure 2-11-3) so the small amount of remnant hornblende would probably retain some of the radiogenic argon generated since its original magmatic crystallization prior to metamorphism. The older date is thus attributed to a mixture of argon from older (Jurassic) hornblende and younger (reset to Cretaceous) sericite.

The whole-rock sample of sericite and carbonate-altered andesite from the Indian mine has a potassium-argon date of 42.7 million years. From Figure 2-11-4, two interpretations might explain this date:

(1) The alteration and the associated ore deposit formed in Eocene time, about 43 Ma.

(2) The alteration and the associated ore deposit formed prior to Eocene time but the potassium-argon "clock" has been reset by Eocene igneous or hydrothermal activity.

The geology of the Indian mine is well described by McGuigan (1985) and Grove (1971). New lead isotope data (Alldrick, Gabites and Godwin, this volume) show that galena from the Galena Cuts open stope has an isotopic composition identical to that of the Porter Idaho mine (MI 103P-089). The lead isotope compositions of galena from the Indian and Porter Idaho mines suggest that this mineralization is significantly younger than that of the Silbak Premier mine, the Scottie Gold mine (MI 104B-034), the Big Missouri deposits and the Silver Butte deposit (MI 104B-150).

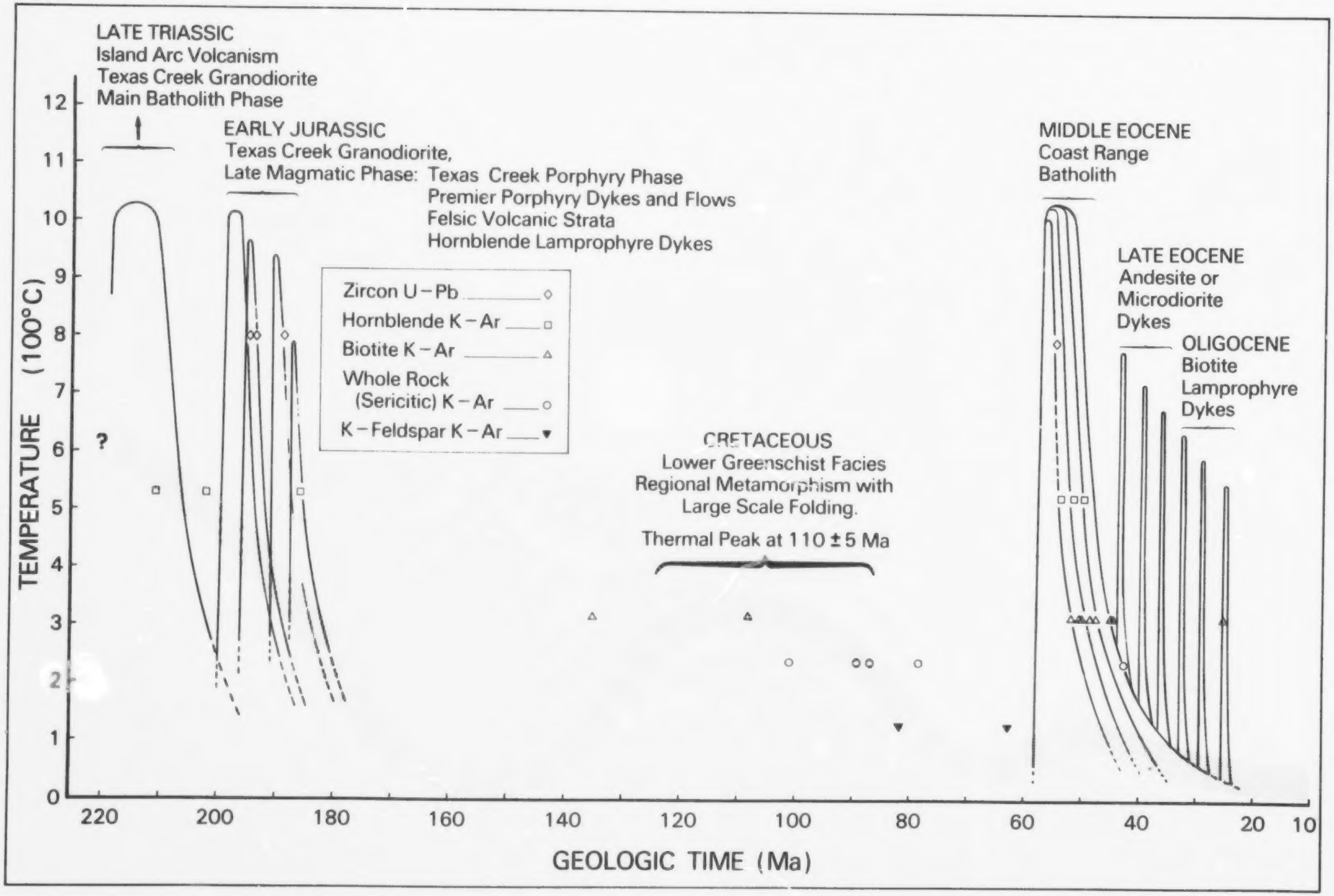


Figure 2-11-4. Isotopic dates versus closure temperatures for the Stewart mining camp; with interpreted thermal, igneous and metamorphic histories.

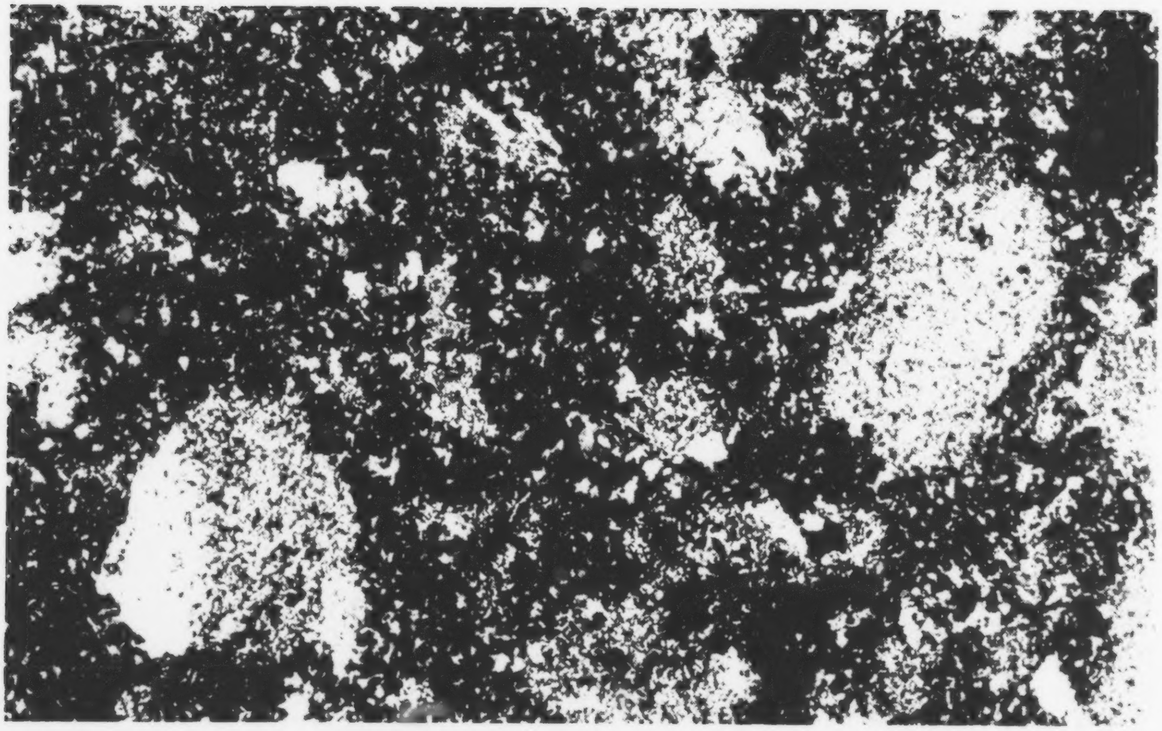


Plate 2-11-1. Photomicrograph of sericite and carbonate-altered andesitic ash tuff, with fine rounded lithic grains. DDH 81-58, 70 feet; crossed nicols; 40 × ; length of total field, 0.6 millimetre.

Plate 2-11-2. Photomicrograph of sericite and carbonate-altered andesitic crystal tuff. Rhombic hornblende fragment is extensively altered to coarse sericite. DDH 81-58, 25 feet; crossed nicols; 40 × ; width of fragment, 0.5 millimetre.

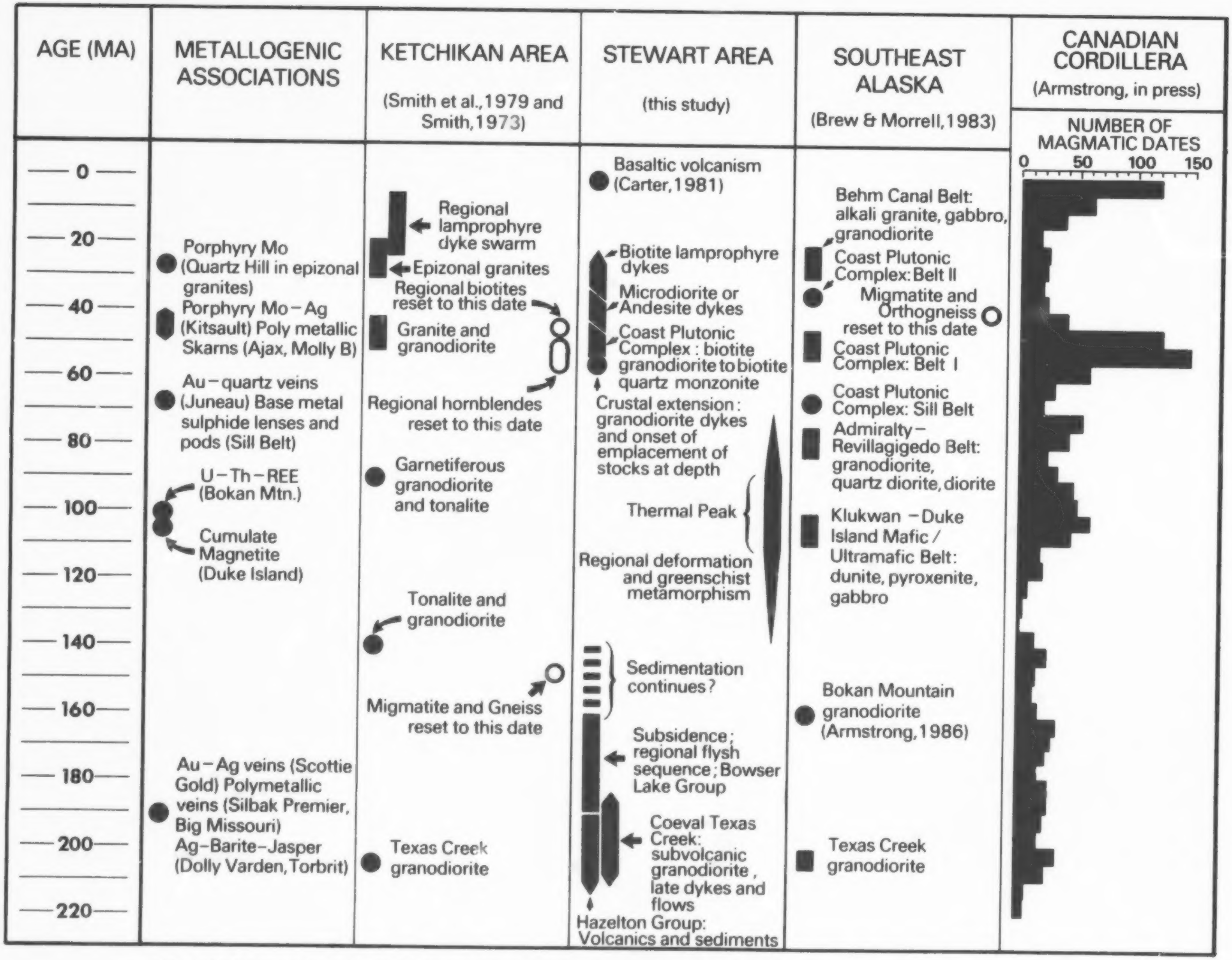

AGE (MA)
METALLOGENIC ASSOCIATIONS
KETCHIKAN AREA
(Smith et al., 1979 and Smith, 1973)
STEWART AREA
(this study)
SOUTHEAST ALASKA
(Brew & Morrell, 1983)
CANADIAN CORDILLERA
(Armstrong, in press)
NUMBER OF MAGMATIC DATES
0
50
100
150
0
20
40
60
80
100
120
140
160
180
200
220
Porphyry Mo (Quartz Hill in epizonal granites)
Porphyry Mo – Ag (Kitsault) Poly metallic Skarns (Ajax, Molly B)
Au – quartz veins (Juneau) Base metal sulphide lenses and pods (Sill Belt)
U – Th – REE (Bokan Mtn.)
Cumulate Magnetite (Duke Island)
Au – Ag veins (Scottie Gold) Polymetallic veins (Silbak Premier, Big Missouri)
Ag–Barite–Jasper (Dolly Varden, Torbrit)
Regional lamprophyre dyke swarm
Epizonal granites
Regional biotites reset to this date
Granite and granodiorite
Regional hornblendes reset to this date
Garnetiferous granodiorite and tonalite
Tonalite and granodiorite
Migmatite and Gneiss reset to this date
Texas Creek granodiorite
Basaltic volcanism (Carter, 1981)
Biotite lamprophyre dykes
Microdiorite or Andesite dykes
Coast Plutonic Complex: biotite granodiorite to biotite quartz monzonite
Crustal extension: granodiorite dykes and onset of emplacement of stocks at depth
Thermal Peak
Regional deformation and greenschist metamorphism
Sedimentation continues?
Subsidence; regional flysh sequence; Bowser Lake Group
Coeval Texas Creek: subvolcanic granodiorite, late dykes and flows
Hazelton Group: Volcanics and sediments
Behm Canal Belt: alkali granite, gabbro, granodiorite
Coast Plutonic Complex: Belt II
Migmatite and Orthogneiss reset to this date
Coast Plutonic Complex: Belt I
Coast Plutonic Complex: Sill Belt
Admiralty – Revillagigedo Belt: granodiorite, quartz diorite, diorite
Klukwan – Duke Island Mafic / Ultramafic Belt: dunite, pyroxenite, gabbro
Bokan Mountain granodiorite (Armstrong, 1986)
Texas Creek granodiorite

Table 2-11-6. Comparison of geologic histories for Stewart, southeast Alaska and the Canadian Cordillera. Bar = significant timespan, solid circle = short timespan or limited dating, open circle = minimum date only.

Alldrick (1985) interpreted the Porter Idaho mine as an Eocene deposit related to emplacement of the 50 Ma Hyder stock, based on field relationships (Alldrick and Kenyon, 1984). The lead isotope data support this Eocene age for the Porter Idaho deposit and indicate that sulphides at the Indian mine were precipitated at the same time. Thus the 43 Ma potassium-argon date for the altered wallrock at the Indian mine probably represents the age of emplacement of the sulphides along the controlling fault structure. Three varieties of Tertiary dykes have been identified on the Indian mine property (McGuigan, 1985), but the nearest major body of Eocene intrusive rock crops out on the summit and the northern slope of Mineral Hill, 3 kilometres south-southwest of the Indian mine.

The formation of the Dago Hill and Silbak Premier deposits must predate the >90 Ma regional metamorphic event, since the isotopic ratios of the alteration envelopes surrounding these deposits are thermally reset by the metamorphism. Black stylolites of insoluble residue are common within the coarse crystalline carbonate gangue at several mineral deposits in the Big Missouri camp (Plate 2-11-3). These stylolites are pressure-solution features that also suggest the deposits predated regional deformation. Fine to medium-grained euhedral pyrite crystals associated with the alteration envelopes at the Big Missouri deposits exhibit well-developed pressure shadows in thin section (Plate 2-11-4), also indicating that the mineralization and alteration predate metamorphism. The age of ore deposition at the Big Missouri, Silbak Premier, Silver Butte, Scottie Gold and similar deposits is estimated at ~190 million years based on field relationships reviewed in Alldrick (1985).

Late biotite lamprophyre dykes crosscut all other rock types, alteration, and mineralization in the Stewart area. These dykes are part of the Tertiary lamprophyre dyke province defined by Smith (1973) who interpreted a Miocene age of emplacement based on field relationships. In the Alice Arm district Carter (1981) reported late Eocene dates from two of these dykes. In separate studies underway at The University of British Columbia, D.A. Brown (Table 2-11-2) and B.D. Devlin (Devlin and Godwin, 1986) have obtained Oligocene dates on biotite lamprophyre dykes in the Stewart and Alice Arm districts respectively. The age range for these dykes is schematically illustrated on Figure 2-11-4 which suggests that Smith's (1973) Tertiary lamprophyre dyke province is dominantly Oligocene in age. These dates contrast with the early Jurassic hornblende potassium-argon date from a hornblende lamprophyre dyke sampled near the Granduc millsite (Table 2-11-2 and Figure 2-11-4).

The new data and interpretations presented in this report allow significant revisions to the geologic history of the district (Table 2-11-5). Recent compilations of isotopic dates for southeast Alaska (Smith *et al.*, 1979 and Brew and Morrell, 1983) and for the whole of the Canadian Cordillera (Armstrong, *in press*) provide a regional and continent-scale context for the geologic history of the Stewart area (Table 2-11-6).

CONCLUSIONS

When isotopic dates from the Stewart mining camp are plotted against closure temperatures for argon loss in minerals, a simple thermal history can be deduced:

(1) Late Triassic to early Jurassic volcanism and coeval emplacement of subvolcanic magma (211 to 190 Ma) was followed by late dyke emplacement (190 to 185 Ma) and by quiescent flysch sedimentation (Toarcian to Callovian, 190 to 160 Ma).

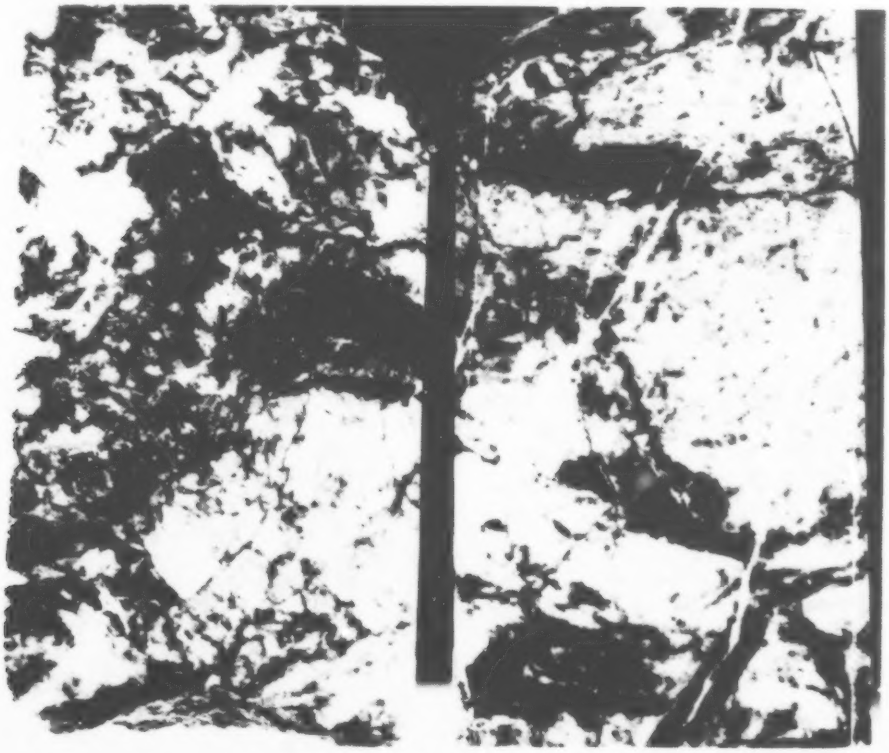


Plate 2-11-3. Coarse calcite-quartz gangue in Dago Hill mineral deposit shows stylolites and fractures lined with black insoluble residue. Scale bar in centimetres; BQ drill core; DDH 81-58.

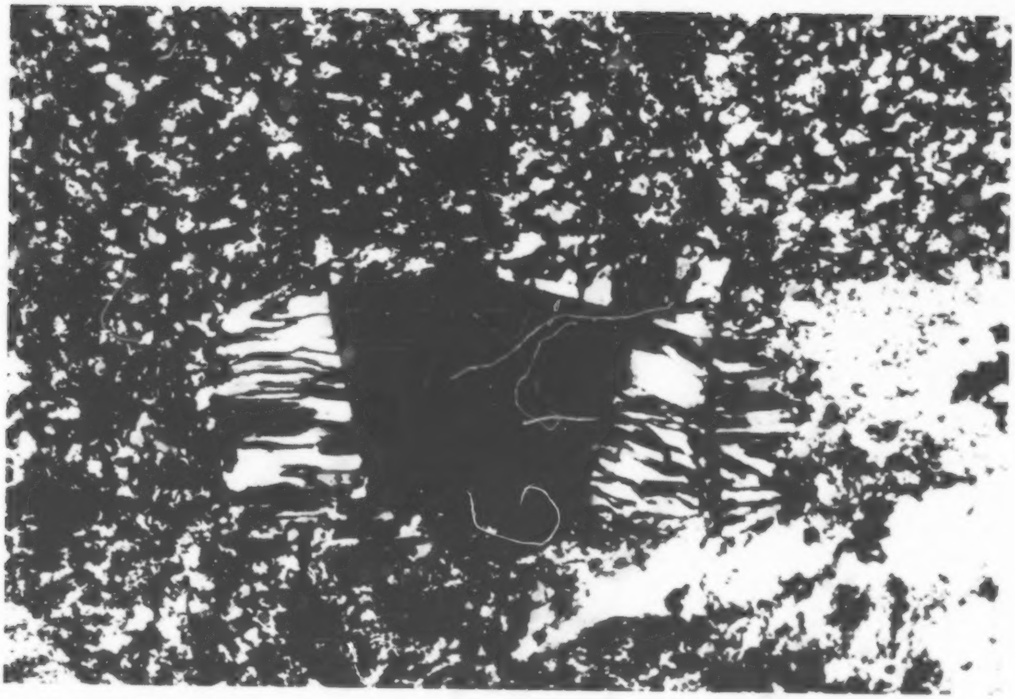


Plate 2-11-4. Pressure shadows of fibrous quartz around euhedral pyrite. DDH 81-58, 22 feet; crossed nicols; 100 × ; width of pyrite crystal, 0.3 millimetre.

TABLE 2-11-5.
GEOLOGIC HISTORY OF THE STEWART MINING CAMP

Age (Ma)	Event
35-25	Emplacement of biotite lamprophyre dykes.
45-35	Emplacement of microdiorite or "andesite" dykes along NNW trend, locally deflected by biotite granodiorite dykes.
48-43	Formation of argentiferous galena-sphalerite-freibergite vein deposits and spatially associated MoS_2 and WO_3 deposits.
55-45	Intrusion of Hyder, Boundary, Davis River, Bitter Creek and Mineral Hill stocks of the Coast Range batholith. Biotite granodiorite to biotite quartz monzonite. Continuing dyke intrusion.
55	Crustal extension and intrusion of major WNW-trending biotite granodiorite dyke swarms marked onset of emplacement of stocks at depth.
110-90	Lower greenschist facies regional metamorphism reaches a thermal peak. Moderate deformation along north-trending fold axes. Major folds and slaty cleavage formed.
190-160	Marine transgression, flysch sedimentation with minor intraformational conglomerates (Unit 4). Relative quiescence.
190-185	Waning magmatic activity marked by emplacement of hornblende lamprophyre dykes at depth.
~190	Subaerial felsic volcanism (Unit 3). Emplacement of dykes at depth. Formation of gold-silver vein and breccia deposits. Deposition of barren pyrite around fumarolic centres at surface.
195-190	Deposition of subaerial epiclastic sediments and interbedded andesitic to dacitic tuffs and flows (Unit 2). (Emplacement of minor dykes at depth?)
195	Intrusion of porphyry phase of Texas Creek granodiorite, Premier Porphyry dykes, and extrusion of Premier Porphyry flows and tuff breccias.
215-195	Andesitic volcanic activity (Unit 1), predominantly subaerial with two periods of marine transgression; coeval intrusion of main phase of Texas Creek granodiorite.

(2) Moderate deformation associated with lower greenschist facies regional metamorphism during Cretaceous time reached its thermal peak about 110 to 90 Ma.

(3) Stocks and dykes of the Coast Range batholith intruded the deformed rocks in early to middle Eocene time, 55 to 45 Ma, followed by a 20-million-year period of microdiorite dyke and biotite lamprophyre dyke emplacement.

A worthwhile field for further studies would be $^{40}Ar/^{39}Ar$ age spectra analysis for mineral separates from andesitic crystal tuffs and from phases of the Texas Creek granodiorite.

ACKNOWLEDGMENTS

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LEAD ISOTOPE DATA FROM THE STEWART MINING CAMP*
(104B/1)

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INTRODUCTION

This report presents new galena lead isotope data from ten mineral occurrences in the Stewart area. The results indicate that the formation of these ten varied deposits can be attributed to just two mineralizing events. The two distinct metallogenic epochs are characterized by different base and precious metal suites, thus lead isotope analysis may be a practical aid to commodity-specific exploration programs and to evaluation of mineral showings at an early stage of a property examination.

In 1986, a suite of galena samples, representing ten deposits on eight properties in the Stewart district, was submitted for lead isotope analysis (Figure 2-12-1 and Tables 2-12-1, 2-12-2 and 2-12-3). Comprehensive bibliographies for each of the sampled deposits are available in the British Columbia Mineral Inventory File (MINFILE) and the MINFILE reference number for each deposit is listed in Table 2-12-1. Detailed descriptions of rock types, their distribution and field relationships in the Stewart area are provided in Alldrick (1985) and are simplified in Figure 2-12-1.

PRINCIPLES OF LEAD ISOTOPE INTERPRETATION

The "lead-lead" or "common lead" method of radiometric dating is based on the accurate measurement of lead isotope abundances (Figure 2-12-2) and on the changing ratios of radiogenic lead isotopes over periods of geologic time (Figure 2-12-3). Galena is used because once it has crystallized, its lead isotopic composition remains constant due to the absence of any radioactive elements in its crystal lattice structure. The reference isotope, ^{204}Pb, is not produced by radioactive decay and so has always been constant in amount (Figure 2-12-2). ^{206}Pb and ^{207}Pb are formed by the radioactive decay of ^{238}U and ^{235}U respectively. ^{235}U has a much shorter half-life [704 million years (Ma)] than ^{238}U (4470 Ma) consequently most of the ^{235}U that was originally present has decayed and the ratio of radiogenic ^{207}Pb to ^{204}Pb has changed little over the past 2000 million years. In contrast, the ratio of radiogenic ^{206}Pb to ^{204}Pb is still increasing relatively rapidly.

Holmes (1946) and Houtermans (1946) first used the exponential radioactive decay law to calculate a curve which corresponded to the evolution or "growth" of the radiogenic lead isotopes with time. The difference in the rate of lead isotope generation from the two uranium parent isotopes is reflected in the progressive flattening of the isotopic lead "growth curve" toward younger ages in Figure 2-12-3. As measurements of lead isotopic ratios accumulated over the next decade, it was noted that the isotopic composition of lead from several conformable ore deposits of various ages were coincident with the Homes-Houtermans growth curve (Stanton and Russell, 1959). By extrapolating the growth curve backward in time according to the radioactive decay law, it coincides with the lead isotope ratios for iron meteorite fragments from Meteor Crater, Arizona at an indicated age of 4600 Ma. This is similar to ages for meteorites and moon rocks calculated by rhubidium-strontium and uranium-lead methods and the 4600-Ma date is interpreted to be the age of formation of the earth.

The growth curve illustrated in Figure 2-12-3 is accurate as a first approximation for lead isotope ratios from many conformable ore deposits, but at more detailed scales this simple curve does not adequately explain isotopic ratios for lead from most epigenetic ores and some conformable ores. Empirically derived mathematical best fit curves, termed "model curves" or "models", have been proposed by many researchers to explain the small scale deviations from the basic growth curve. The reader is referred to major papers by Armstrong (1968), Stacey and Kramers (1975), Cumming and Richards (1975), Doe and Zartman (1979), Godwin and Sinclair (1982), Andrew, Godwin and Sinclair (1984) and Gulson (1986) for applications of "model curves" to lead isotope data.

ANALYTICAL METHODS

All the lead analysed was extracted from medium to coarse-grained hand-picked galena. Sample preparation and lead isotope analyses were completed by J.E. Gabites in the geochronology laboratory, Department of Geological Sciences, The University of British Columbia. Lead isotope ratios were measured on a Vacuum Generators Isomass 54R solid source mass spectrometer linked to a Hewlett-Packard HP-85 computer. Samples were loaded using phosphoric acid and silica gel.

In-run precision, or machine error, is usually better than 0.01 per cent standard deviation. Repeated measurement of the Broken Hill standard (BHS-UBC1) and systematic analyses of duplicates were used to monitor the analytical precision of the runs. Isotope ratios were normalized to the BHS values of Richards *et al.* (1981). The minimum variation observed in duplicate analyses is less than 0.05 per cent.

Even under optimum analytical conditions errors arise from fractionation processes which cause relative depletion of the lighter lead isotopes with respect to the heavier ones. Isotopic fractionation is the main source of analytical variations in single filament spectrometers. Another analytical error is associated with the measurement of the low intensity ^{204}Pb spectrometer peak due to the low abundance of this isotope. The slopes of the fractionation error and the ^{204}Pb error are illustrated on each diagram in Figure 2-12-4.

RESULTS

The results of these new galena lead isotope analyses are listed in Tables 2-12-2 and 2-12-3 and plotted as conventional lead isotope diagrams on Figures 2-12-4A, 4B and 4C. All data reduction for this report has been calculated with the decay constants recommended by the Subcommission on Geochronology of the International Union of Geological Sciences (Steiger and Jäger, 1977).

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

Table 2-12-1 lists the deposit name, location, host lithology, deposit type and the British Columbia Mineral Inventory File (MINFILE) number. Table 2-12-2 presents galena lead isotope data from six deposits on four properties that plot as a discrete cluster, marked Cluster 1, on Figure 2-12-4A, 4B and 4C. Table 2-12-3 lists galena lead isotope data from four deposits that plot as a second discrete cluster, marked Cluster 2, on Figure 2-12-4A, 4B and 4C. To simplify the plots and improve clarity, only the ten averaged values indicated on Tables 2-12-2 and 2-12-3 have been plotted on Figure 2-12-4.

INTERPRETATION

The following discussion is based mainly on relationships between uranogenic lead (^{206}Pb, ^{207}Pb) and thoriogenic lead (^{208}Pb) shown on Figures 2-12-4A and 2-12-4B. The plot in Figure 2-12-4C is primarily used to analyse the effects of ^{204}Pb error, which is small for this data set; fractionation error is also minimal.

"Common lead" isotope data can yield crude absolute age determinations if a suitable model curve is available for interpretation. A model may also provide indications about the source of elemental lead in an ore deposit. Development of such a model requires a large database from similar rocks and sulphides which must be assembled before meaningful absolute age determinations can be attempted. There is not enough spread in the Stewart data points to construct an empirical model curve by graphical means. However, smaller lead isotope data sets are useful for indicating relative age relationships between deposits, and between deposits and their host rocks. The interpretation of relative, nonabsolute age relationships from lead isotope data is known as "fingerprinting".

Fingerprint interpretation of lead isotope data is a simple powerful tool when combined with other geological data. The following six interpretations are derived from the data presented in Figures 2-12-1, 2-12-3 and 2-12-4B.

(1) On Figure 2-12-3, the position of the field of Figure 2-12-4B indicates that all the deposits sampled in this study are Phanerozoic.

(2) Comparing the relative positions of the two data clusters of Figure 2-12-4B with the progressive evolution of lead isotope ratios shown in Figure 2-12-3 suggests that the galena of the deposits in Cluster 2 might be significantly younger than the galena of Cluster 1 deposits. This relative age relationship is consistent with interpretations based on geological evidence and can be confirmed mathematically by applying the radioactive decay law.

(3) The two tight clusters of data shown on Figure 2-12-4B clearly define two separate metallogenic events in the Stewart area.

(4) The tightness of the two data clusters indicates that each of the two ore-forming events was a short-lived episode in geologic time.

(5) Both clusters of data represent deposits that are distributed over a 30-kilometre strike length, thus the two metallogenic processes that formed these deposits were both regional phenomena.

(6) Although the Indian mine and the Silbak Premier mine are less than 2 kilometres apart, the data indicate that these deposits are not genetically related and that they formed at significantly different times, with the Indian mine being the younger of the two.

Alldrick (1985) and Alldrick *et al.* (this volume) argued that the two ore-forming episodes were not closely related genetic processes. Specifically, Cluster 1 deposits formed cogenetically with calc-alkaline Hazelton Group volcanic rocks of the Stikinia terrane about 190 million years ago. The Cluster 2 deposits are epigenetic veins related to Eocene intrusion of dominantly granodioritic plutons that were generated by subduction processes.

The data clusters of Figure 2-12-4 can be used to generally support the interpretation of Jurassic and Tertiary metallogenic epochs, yet also indicate that the mineralizing events are genetically distinct. If an age can be assigned to one of the two data clusters based on geological or other isotopic evidence, an approximate elapsed time between the two data clusters can be calculated using the radioactive decay law. When a date of 48 Ma is assigned to the group mean of Cluster 2, the group mean of Cluster 1 yields a calculated age of 210 Ma. This latter date is close to the 190-Ma age interpreted for the Cluster 1 metallogenic event by Alldrick *et al.* (this volume). This calculation also yields a ratio of the parent ^{238}U to the reference ^{204}Pb isotope of 14.0, known as the μ value. This value for μ is unnaturally high (μ values for all model curves lie between 8.2 and 12.2), and therefore indicates that the galena lead in the deposits of Cluster 2 is not simply remobilized or evolved from the same lead source as Cluster 1 deposits.

When these interpretations are combined with other studies, they provide corroborative support for many established interpretations, raise questions about some earlier theories, and suggest an application for systematic lead isotope analysis in exploration programs in the Stewart area.

The data indicate that the ore at the Indian mine is cogenetic with mineralization at the Porter Idaho mine, the Bayview prospect and the Jarvis vein. The Porter Idaho mine and Bayview prospect were interpreted as Eocene age deposits based on field relationships (Alldrick, 1985 and Alldrick and Kenyon, 1984) and on potassium-argon dates from associated intrusive rocks (Smith, 1977). This interpretation is further supported by a new potassium-argon date of 42.7 Ma from the altered host rocks at the Indian mine (Alldrick, *et al.*, this volume). The indicated Middle Eocene age of these mineral deposits coincides with the age of many intrusive rocks along the eastern margin of the Coast Plutonic Complex (Carter, 1981). Significantly, this epoch also coincides with the age of many major porphyry molybdenum deposits, with peripheral high-grade silver veins and disseminations, that are also distributed along the eastern margin of the Coast Plutonic Complex, for example, Kitsault (MI 103P-120), Ajax (MI 103P-223), Tidewater (MI 103P-111), Molly Mack (MI 103P-228), Roundy Creek (MI 103P-234), Bell Moly (MI 103P-113), Valley Ridge (MI 103P-231), Snafu (MI 103P-232), Kay (MI 103P-225) and others (Carter, 1981). Woodcock and Hollister (1978) concluded that this zone was the locus for a major metallogenic province of molybdenum (± tungsten) porphyry deposits throughout North America. In the Stewart region, formation of these deposits took place during a restricted interval of Middle Eocene time, 48-43 million years ago.

Alldrick (1985, page 337) concluded that the Indian mine ores formed at the same time as oreshoots at the nearby Silbak Premier mine, on the basis of textural and mineralogical similarities between the coarse-grained galena-sphalerite ore found at the Indian mine and in ore zones at the deepest levels of the Silbak Premier mine, termed the Northern Lights or Premier Border zone (MI 104B-53). The single lead isotope determination for the Silbak Premier mine comes from a sample near the upper workings, 500 metres above the Northern Lights zone. The deep level galena-sphalerite ores of the Silbak Premier may be genetically related to the overlying oreshoots (Cluster 1), or they may be younger, superimposed sulphide deposits genetically related to Indian mine mineralization (Cluster 2).

The deposits of Cluster 1 and similar deposits in the Stewart district are either gold-silver-pyrrhotite veins, such as the Scottie

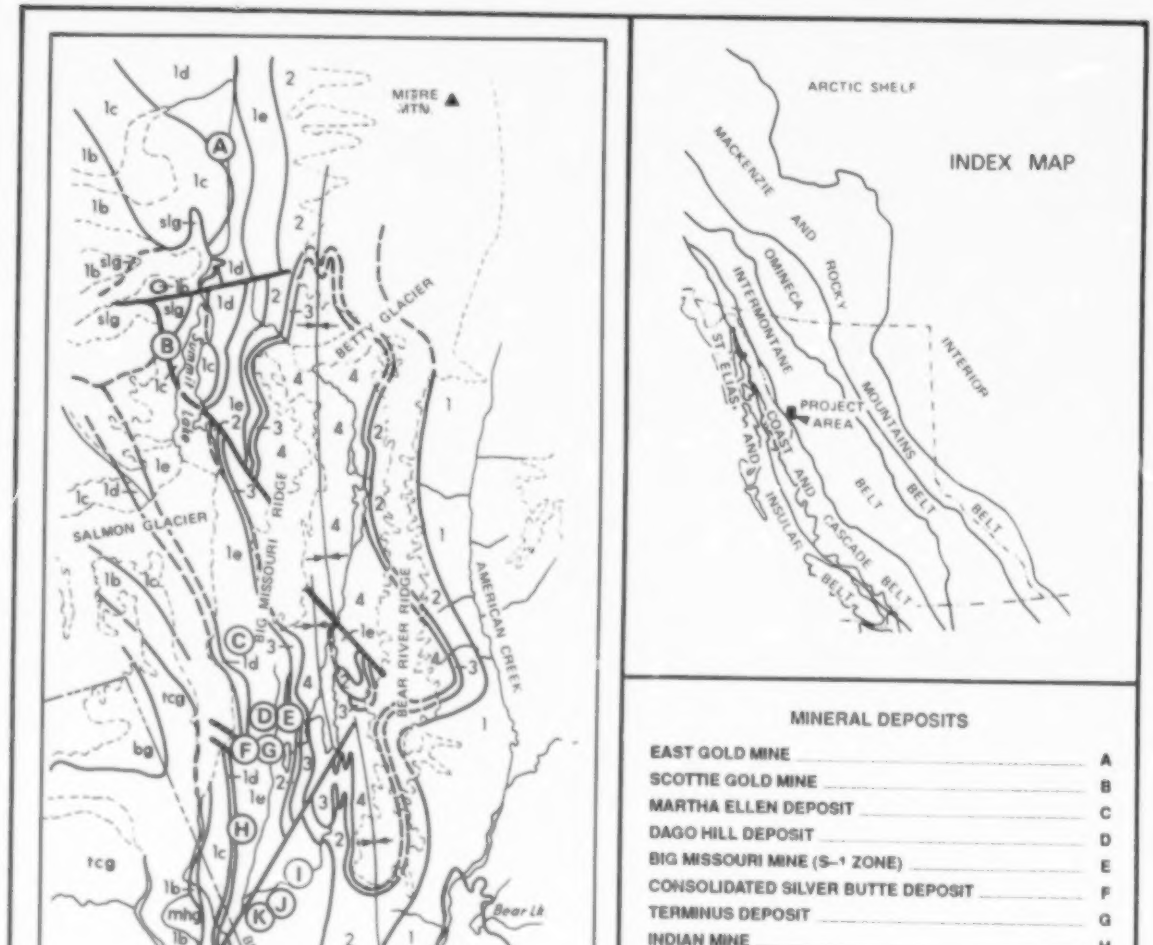

INDEX MAP
ARCTIC SHELF
MACKENZIE AND ROCKY MOUNTAINS BELT
OMINECA BELT
INTERMONTANE BELT
ST. ELIAS AND COAST AND CASCADE BELT
INSULAR BELT
INTERIOR
PROJECT AREA
MINERAL DEPOSITS
EAST GOLD MINE A
SCOTTIE GOLD MINE B
MARTHA ELLEN DEPOSIT C
DAGO HILL DEPOSIT D
BIG MISSOURI MINE (S-1 ZONE) E
CONSOLIDATED SILVER BUTTE DEPOSIT F
TERMINUS DEPOSIT G
INDIAN MINE H
SEBAKWE MINE I
B.C. SILVER MINE J
SILBAK PREMIER MINE K
RIVERSIDE MINE L
JARVIS VEIN M
BAYVIEW DEPOSIT N
PROSPERITY AND PORTER IDAHO MINES O
LEGEND
hqm, bg, mhg Eocene biotite granodiorite stocks
tcg, slg Lower Jurassic hornblende granodiorite stocks
4 Argillite, siltstone, sandstone
3 Dacite pyroclastic formation
2 Epiclastic rocks, hematitic
1e Andesite tuffs and flows
1d Argillite, siltstone
1c Andesite tuffs
1b Argillite, siltstone
1a Andesite tuffs
MITRE MTN.
BETTY GLACIER
SALMON GLACIER
Summit Lake
BIG MISSOURI RIDGE
BEAR RIVER RIDGE
AMERICAN CREEK
Bear Lk
Bitter Cr. Monzonite
BRITISH COLUMBIA
ALASKA
BEAR RIVER
SALMON RIVER
STEWART
HYDER
RYAN GLACIER
55°55'
130°00'
N
0 5 Kilometres

Figure 2-12-1. Geology and mineral deposits of the Stewart area (from Alldrick, 1985).

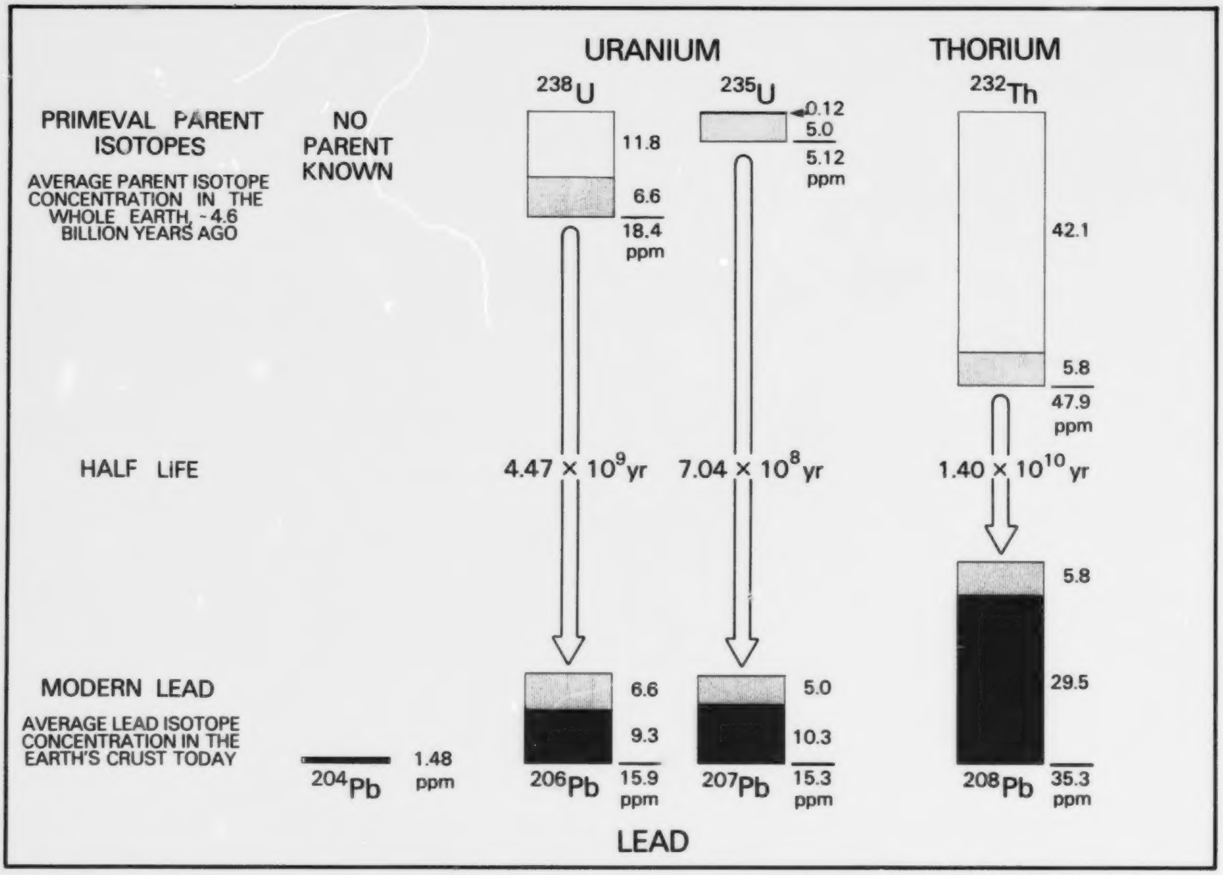

URANIUM
THORIUM
238U
235U
232Th
PRIMEVAL PARENT ISOTOPES
AVERAGE PARENT ISOTOPE CONCENTRATION IN THE WHOLE EARTH, ~4.6 BILLION YEARS AGO
NO PARENT KNOWN
11.8
6.6
18.4 ppm
0.12
5.0
5.12 ppm
42.1
5.8
47.9 ppm
HALF LIFE
4.47 × 10⁹yr
7.04 × 10⁸yr
1.40 × 10¹⁰yr
5.8
29.5
MODERN LEAD
AVERAGE LEAD ISOTOPE CONCENTRATION IN THE EARTH'S CRUST TODAY
204Pb
1.48 ppm
6.6
9.3
206Pb
15.9 ppm
5.0
10.3
207Pb
15.3 ppm
208Pb
35.3 ppm
LEAD

Figure 2-12-2. Isotopic relationships between uranium, thorium and lead in the earth's crust. Dark grey = primeval lead; light grey = uranium and thorium decayed to radiogenic lead during 4.6 billion years; white = radioactive parent isotopes that still remain [modified from Cannon *et al*. (1961), Tatsumoto *et al*. (1973) and Steiger and Jager (1977)].

TABLE 2-12-1
DEPOSIT LOCATION, HOST UNIT, DEPOSIT TYPE AND MINFILE NUMBER

BC Lead File Deposit Number	Deposit Name	NTS Number (MINFILE Number)	Lat. N Long. W (degrees)	Lithology	Deposit Type
30415	Big Missouri	104B/01E (104B-046)	56.13 130.03	Unuk River: altered andesite tuff	Vein
30492	Prosperity-Porter Idaho	103P/13W (104B-089)	55.91 129.94	Unuk River: dacitic and andesite tuff	Vein in shear
30493	Scottie Gold	104B/01E (104B-074)	56.22 130.09	Unuk River: andesite tuff	Mesothermal Au-Po vein
30494	Silbak Premier	104B/01E (104B-054)	56.05 130.01	Unuk River: altered andesite tuff	Epithermal vein
30495	Consolidated Silver Butte	104B/01E (104B-095)	56.11 130.03	Unuk River: altered andesite tuff	Epithermal Au-Ag vein
30765	Bayview	103P/13W (103P-051)	55.96 129.98	Unuk River: hornfelsed argillite	Vein
30871	Jarvis	1030/16E (1030-024)USA	55.99 130.07	Texas Creek (HB) granodiorite	Vein
30939	Indian (New Indian)	104B/01E (104B-031)	56.08 130.03	Unuk River: andesitic and lapilli tuff	Vein in shear

TABLE 2-12-2
LEAD ISOTOPE DATA FOR CLUSTER 1 DEPOSITS

Plotted Values on Figure 2-12-4	Sample No.	Deposit/Sample Name	Quality	206_{Pb} 204_{Pb} % error	207_{Pb} 204_{Pb} % error	208_{Pb} 204_{Pb} % error	206_{Pb} 207_{Pb} % error	206_{Pb} 208_{Pb} % error
	30415-006	Big Missouri (Creek), SR-114	Good	18.820 ± 0.02	15.615 ± 0.02	38.456 ± 0.02	1.20526 ± 0.01	0.489399 ± 0.01
	30415-007	Big Missouri (Terminus), SR-169	Good	18.823 ± 0.02	15.609 ± 0.02	38.435 ± 0.03	1.20588 ± 0.01	0.489729 ± 0.02
	30415-008	Big Missouri (Martha Ellen), 1	Good	18.824 ± 0.03	15.610 ± 0.02	38.458 ± 0.03	1.20587 ± 0.01	0.489467 ± 0.01
	30415-008R	Big Missouri (Martha Ellen), 1	Good	18.822 ± 0.01	15.611 ± 0.01	38.453 ± 0.02	1.20571 ± 0.01	0.489475 ± 0.02
	30415-008A	Big Missouri (Martha Ellen N = 2)	Good	18.823 ± 0.00	15.611 ± 0.00	38.456 ± 0.01	1.20579 ± 0.00	0.489471 ± 0.00
*	30415-Avg	Big Missouri (N = 3)	Good	18.822 ± 0.00	15.612 ± 0.01	38.449 ± 0.02	1.20564 ± 0.00	0.489533 ± 0.00
*	30493-001	Scottie Gold, SG-8	Good	18.804 ± 0.02	15.608 ± 0.01	38.426 ± 0.02	1.20472 ± 0.02	0.489352 ± 0.01
*	30494-007	Silbak Premier, SR-45	Good	18.825 ± 0.01	15.611 ± 0.01	38.421 ± 0.02	1.20589 ± 0.01	0.489966 ± 0.01
	30495-001	Consol. Silver Butte, SR-168	Good	18.828 ± 0.02	15.619 ± 0.02	38.474 ± 0.02	1.20548 ± 0.01	0.489361 ± 0.01
	30495-001D	Consol. Silver Butte, SR-168	Fair	18.812 ± 0.04	15.604 ± 0.04	38.432 ± 0.04	1.20545 ± 0.01	0.489473 ± 0.01
*	30495-001A	Consolidated Silver Butte (N = 2)	Good	18.820 ± 0.02	15.612 ± 0.02	38.453 ± 0.06	1.20547 ± 0.00	0.489416 ± 0.01
*	Jurass-AVG	AVG of Jurassic Group		18.818 ± 0.02	15.611 ± 0.00	38.437 ± 0.03	1.20544 ± 0.00	0.489567 ± 0.00

D = duplicate (new chemistry).
R = sample repeat; repeat analysis (same chemistry).
A = Sample average.
AVG = deposit average.

Errors on all averages are %2σ.

Broken Hill Standard (Richard, 1981): 6/4 16.004 (.001), 7/4 15.390 (.007), 8/4 35.651 (.017).

TABLE 2-12-3
LEAD ISOTOPE DATA FOR CLUSTER 2 DEPOSITS

Plotted Values on Figure 2-12-4	Sample No.	Deposit/Sample Name	Quality	206_{Pb} / 204_{Pb} % error	207_{Pb} / 204_{Pb} % error	208_{Pb} / 204_{Pb} % error	206_{Pb} / 207_{Pb} % error	206_{Pb} / 208_{Pb} % error
	30492-001	Prosperity-Porter Idaho, PI-7	Good	19.130 ± 0.03	15.627 ± 0.02	38.644 ± 0.03	1.22418 ± 0.01	0.495027 ± 0.01
	30492-002	Prosperity-Porter Idaho, PI-10	Good	19.116 ± 0.02	15.624 ± 0.01	38.616 ± 0.02	1.22351 ± 0.01	0.495020 ± 0.01
	30492-003	Prosperity-Porter Idaho, PI-11	Good	19.114 ± 0.02	15.610 ± 0.01	38.589 ± 0.03	1.22448 ± 0.01	0.495317 ± 0.02
	30492-003R	Prosperity-Porter Idaho, PI-11	Good	19.122 ± 0.02	15.619 ± 0.01	38.614 ± 0.02	1.22433 ± 0.01	0.495214 ± 0.01
	30492-003A	Prosperity-Porter Idaho (N = 2)	Good	19.118 ± 0.01	15.615 ± 0.01	38.602 ± 0.03	1.22441 ± 0.00	0.495266 ± 0.01
*	30492-AVG	Prosperity-Porter Idaho (N = 3)	Good	19.121 ± 0.02	15.622 ± 0.01	38.621 ± 0.04	1.22403 ± 0.00	0.495104 ± 0.00
	30765-002	Bayview, Pit 3/1	Good	19.153 ± 0.01	15.616 ± 0.01	38.608 ± 0.01	1.22651 ± 0.01	0.496086 ± 0.00
	30765-003R	Bayview, Pit 3/2	Good	19.151 ± 0.01	15.623 ± 0.01	38.623 ± 0.02	1.22575 ± 0.01	0.495707 ± 0.01
	30765-004	Bayview, Pit 3/3	Good	19.152 ± 0.01	15.622 ± 0.00	38.633 ± 0.01	1.22594 ± 0.01	0.495752 ± 0.01
*	30765-AVG	Bayview	Good	19.152 ± 0.00	15.620 ± 0.01	38.621 ± 0.02	1.22607 ± 0.00	0.495848 ± 0.00
	30871-001	Jarvis, JA-1	Good	19.164 ± 0.03	15.607 ± 0.02	38.579 ± 0.04	1.22792 ± 0.02	0.496755 ± 0.03
	30871-002	Jarvis, JA-7	Good	19.158 ± 0.01	15.625 ± 0.01	38.616 ± 0.01	1.22614 ± 0.01	0.496131 ± 0.00
	30871-003	Jarvis, JA-11	Good	19.174 ± 0.02	15.635 ± 0.01	38.656 ± 0.02	1.22631 ± 0.01	0.496011 ± 0.02
*	30871-AVG	Jarvis (N = 3)	Good	19.165 ± 0.02	15.622 ± 0.03	38.617 ± 0.08	1.22679 ± 0.00	0.494299 ± 0.00
	30939-001	Indian (New Indian), IM-1	Good	19.150 ± 0.02	15.625 ± 0.01	38.665 ± 0.03	1.22556 ± 0.01	0.495273 ± 0.02
	30939-002	Indian (New Indian), IM = 1A	Good	19.159 ± 0.02	15.621 ± 0.02	38.650 ± 0.02	1.22644 ± 0.01	0.495696 ± 0.01
*	30939-AVG	Indian (New Indian, N = 2)	Good	19.155 ± 0.01	15.623 ± 0.01	38.658 ± 0.02	1.22600 ± 0.00	0.495485 ± 0.00
*	Tertiar-AVG	AVG of Tertiary Group	Good	19.148 ± 0.04	15.622 ± 0.00	38.629 ± 0.04	1.22572 ± 0.00	0.495684 ± 0.00

D = duplicate (new chemistry).
R = sample repeat; repeat analysis (same chemistry).
A = Sample average.
AVG = deposit average.

Errors on all averages are %2σ.

Broken Hill Standard (Richard, 1981): 6/4 16.004 (.001), 7/4 15.390 (.007), 8/4 35.651 (.017).

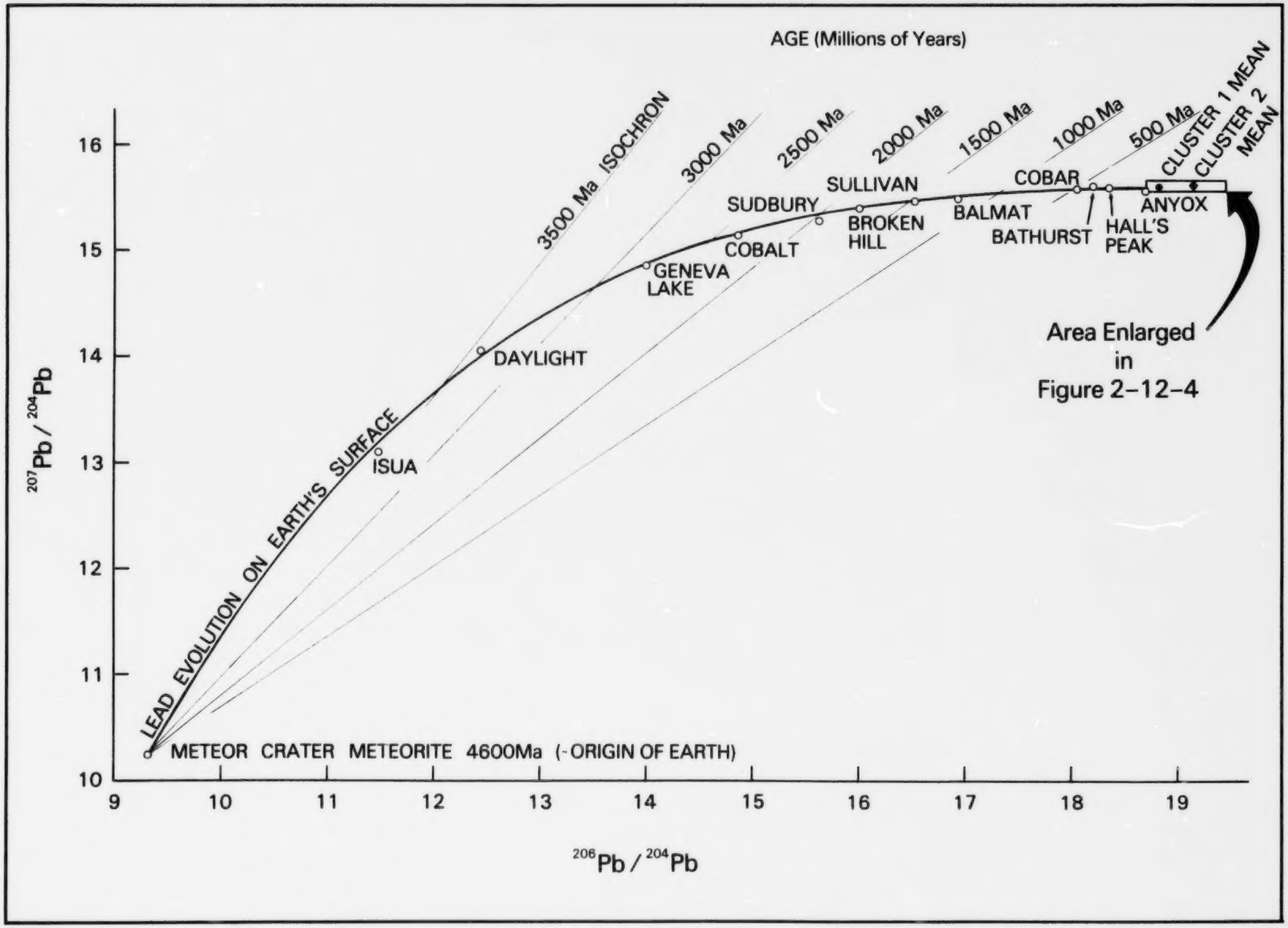
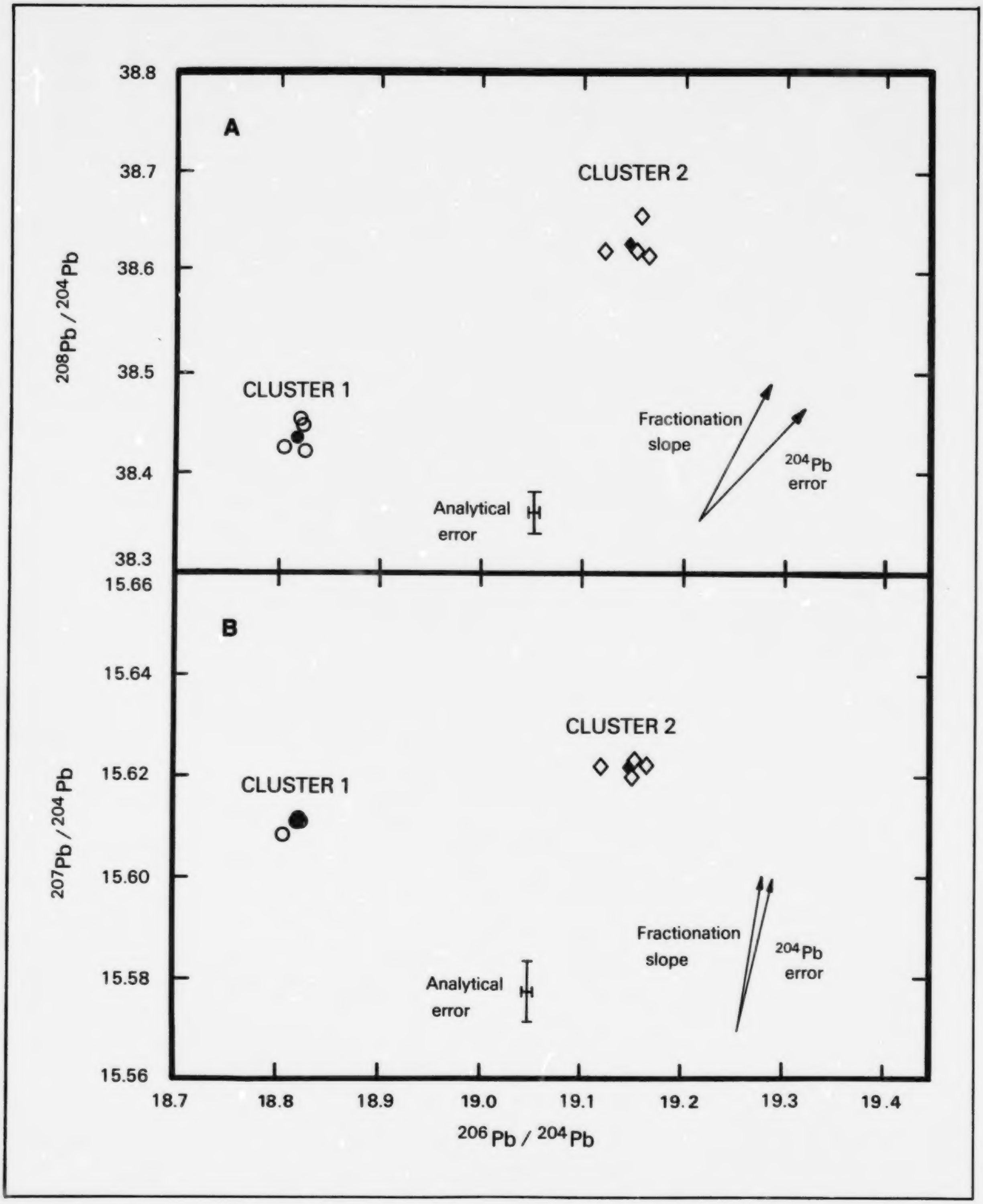


Figure 2-12-3. Growth curve for lead isotope evolution showing distribution of Cluster 1 and Cluster 2 data sets [modified from Armstrong (1968) and Moorbath (1985); data from Cumming and Richards (1975), Alldrick (1986) and this study].



A
B
CLUSTER 1
CLUSTER 2
Fractionation slope
^{204}Pb error
Analytical error
^{208}Pb / ^{204}Pb
38.3
38.4
38.5
38.6
38.7
38.8
^{207}Pb / ^{204}Pb
15.56
15.58
15.60
15.62
15.64
15.66
^{206}Pb / ^{204}Pb
18.7
18.8
18.9
19.0
19.1
19.2
19.3
19.4

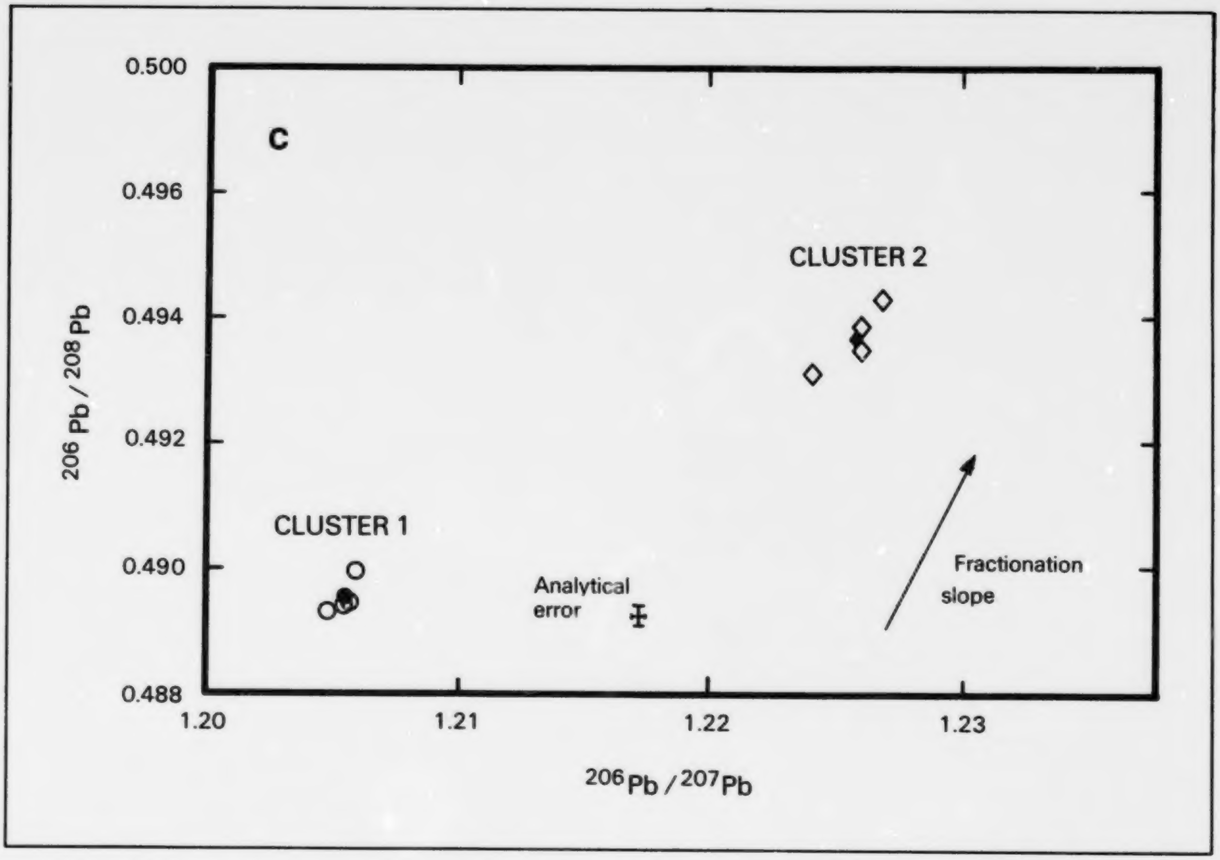


Figure 2-12-4. Plots of averaged lead isotopic ratios for deposits located on Figure 2-12-1 and listed in Tables 2-12-2 and 2-12-3. ○ = deposits with Jurassic lead signature, ◇ = deposits with Tertiary lead signature. Closed symbols represent group means. Analytical error shown is 2σ from 46 analyses of Broken Hill galena standard.

Gold mine, or gold-silver-lead-zinc-copper deposits such as the Silbak Premier mine. In contrast, deposits of Cluster 2 are silver-lead-zinc veins characterized by high silver grades and by spatially associated molybdenum and/or tungsten occurrences. In small outcrop or trench exposures the structural, textural and mineralogical differences between the deposits are not always evident. For example, samples from the Creek zone at the Big Missouri property and from the Number 3 trench at the Bayview prospect are mineralogically similar in hand sample. As Figure 2-12-4B shows, the lead isotope ratios clearly distinguish the different ore-forming episodes that produced the deposits.

The same indications might be achieved by assays; sulphide-rich grab samples show values up to 18 ppm gold and 323 ppm silver at the Creek zone while a grab sample from the Bayview trench assayed 1 ppm gold and 3472 ppm silver. Unfortunately assays of a few fist-sized grab samples are unreliable indicators of the overall gold and silver grades of the entire mineralized zone, whereas two or three lead isotope ratios from galena crystals would be representative for the deposits. A lead isotope analysis from galena in a small exposure or in a weakly mineralized vein would indicate whether the mineral occurrence was related to the earlier gold-silver(-base metal) event or to the later silver-lead-zinc(-molybdenum-tungsten) mineralizing episode. This distinction might govern the urgency, intensity or necessity for further exploration work.

CONCLUSIONS

Lead isotope data from the Stewart mining camp do not provide absolute age dates for the formation of mineral deposits, but the relative distributions of data are consistent with absolute dates determined in other studies. The genesis of ten varied mineral deposits can be attributed to just two mineralizing events. The formation of more than one hundred other mineral occurrences in the district may be related to these same two ore-forming episodes. Both metallogenic epochs were brief, regional-scale phenomena. Deposits from the younger mineralizing episode may be emplaced adjacent to older deposits.

In the Stewart area, routine lead isotope analysis would be a practical aid for exploration programs focused on specific commodities. The method is an effective technique for evaluating the commodity potential of a small mineral showing, or for setting exploration priorities on properties that host several varied mineral occurrences.

ACKNOWLEDGMENTS

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obtained through the Canada/British Columbia Mineral Development Agreement grant to Dr. C.I. Godwin at The University of British Columbia. Analyses were carried out at the Geochronology Laboratory directed by Dr. R.L. Armstrong at the Department of Geological Sciences, The University of British Columbia.

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GOLDEN BEAR PROJECT*
(104K/1)

By T. G. Schroeter

INTRODUCTION

The Golden Bear gold deposit (Mineral Inventory 104K-079) previously called the Muddy Lake gold deposit (Schroeter, 1985, 1986) is located 137 kilometres west of Dease Lake. In the spring of 1986 North American Metals Corp. negotiated a joint venture agreement to acquire a 50-per-cent interest in the Chevron Minerals Ltd. Golden Bear property. Diluted geological reserves on the 12 140-hectare property were calculated by Chevron at 1.18 million tonnes with an average grade of 11.5 grams of gold per tonne; equivalent to approximately 13.6 tonnes of gold. These drill-indicated reserves are contained in two zones:

(1) **Bear Main:** 765 000 tonnes of diluted geological reserves grading 13.3 grams of gold per tonne with a cut-off grade of 6.86 grams per tonne — in part open pittable;

(2) **Fleece Bowl:** 415 400 tonnes of diluted geological reserves grading 8.15 grams of gold per tonne — underground (Wober and Shannon, 1985).

The Totem Silica zone is geologically favourable and the potential for increasing reserves is considered very good.

Chevron has invested $12.3 million on development of the Golden Bear property and completed some 18 300 metres of surface diamond drilling. North American Metals has taken over as operator of the project and can earn a 50-per-cent interest by spending $9 million on further development. The 1987 development program is expected to cost $3.3 million with a feasibility study planned for spring 1987 and mine production in late 1988.

A brief visit to the property was made on November 4 and 5, 1986; this report presents some new age data and chemical analyses, and provides comment on ore genesis. Locations of the samples reported are shown in Figure 2-13-1.

BEAR MAIN ZONE

Development during 1986 was concentrated on the Bear Main zone (Plate 2-13-1). Surface and underground diamond drilling and crosscuts have intersected the zone over a strike length in excess of 325 metres and further testing is planned (Figure 2-13-2). Recent assay results both from drill core and underground sampling indicate higher grades than expected. For example, surface drill hole 86-127 returned 37.03 grams of gold per tonne over 16.76 metres and a panel sample from underground on the 3809E crosscut (Figure 2-13-2) assayed 43.54 grams of gold per tonne over a width of 9.14 metres (North American Metals Corp., October 28, 1986, Press Release). Substantial widths of lower grade mineralization are present above and below some intersections.

The Bear Main zone consists of oxide mineralization, estimated to contain 208 600 tonnes grading 14.4 grams of gold per tonne and an underlying refractory zone containing 556 900 tonnes grading 12.9 grams of gold per tonne. A significant part of these reserves is available for open-pit mining with a stripping ratio of approximately 6:1 (J. Franzen, personal communication, 1986). Exploration for additional reserves is currently in progress in the 1400-metre level adit. An updated reserve estimate will be available on completion of the program.

TABLE 2-13-1.
AGE DATING FROM GOLDEN BEAR AND AREA

Field No.	Lab No.	Location Longitude	Location Latitude	Zone	Rock Type	Minerals	%K (mean n = 5)	Ar^{40*} $\times 10^{-10}$ mol/g	% Ar	Apparent Age (Ma)	Comments
ML — 81	31643M	58°13′	132°17′	Bear Main	Talc-sericite tuff	Sericite	8.35±0.12	31.300	96.8	204±7	Drill core @ 162.9 to 163.3 m
ML — 92	31644M	58°14′	132°17′	Totem Silica	Sericitic tuff	Sericite	7.26±0.10	26.226	93.4	197±7	Drill core @ 59 m
ML — 93	31645M	58°13.5′	132°17′	Fleece Bowl	Sericitic tuff	Whole rock (sericite concentrate)	4.34±0.06	14.160	87.0	179±6	Drill core @ 37.2 m
ML — 95	31646M	58°14′	132°17′	Totem Silica	Sericitic tuff	Sericite	7.40±0.05	27.928	98.3	205±7	Drill core @ 94.2 to 94.4 m
NIE-85-1	31647M	58°21′	132°18′	NIE (2 oz. Notch)	Hornblende feldspar porphyry dyke	Hornblende	1.45±0.02	4.105	94.4	156±5	Hand specimen
WH — 70	—	58°16′21″	132°24′30″	Ram/Tut	Albitite	Whole rock	0.474±0.01	1.473	79.2	171±6	Hewgili thesis (1985)
		58°12′50″	132°17′	Bear Main	Sericitic tuff	Whole rock (sericite concentrate)	6.94±0.08	22.437	96.7	177±6	Chevron (1984)

* Radiogenic Ar
Constants: $\lambda^{40} K_e = 0.581 \times 10^{-1}$ yr^{-1}; $\lambda^{40} K_\beta = 4.96 \times 10^{-10}$ yr^{-1} ; K/K = 1.67×10^{-4}
%K determined by the Analytical Laboratory, British Columbia Ministry of Energy, Mines and Petroleum Resources, Victoria.
Ar determination and age calcuiation by J.E. Harakal, The University of British Columbia.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

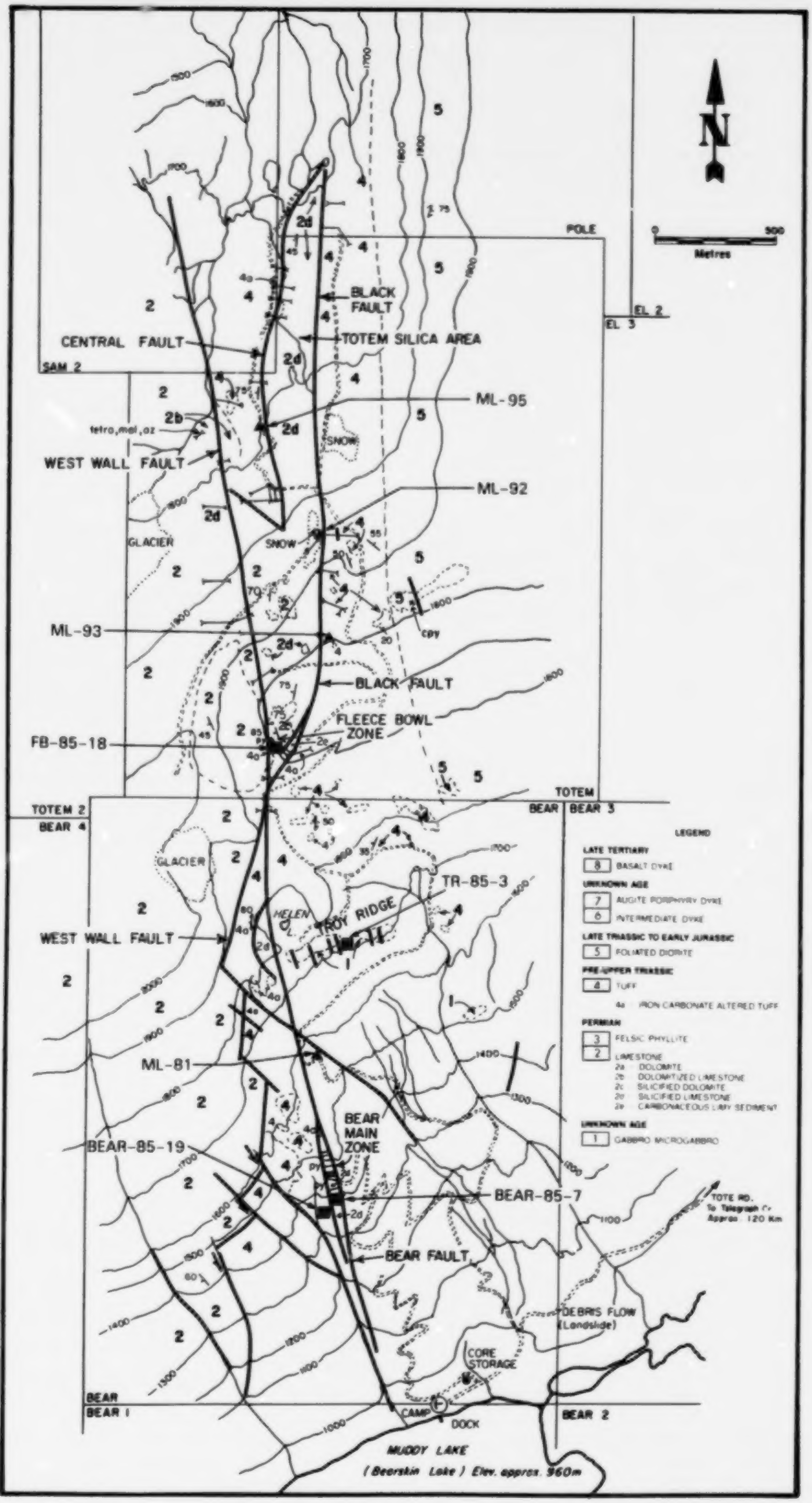
N
0
500
Metres
POLE
EL 2
EL 3
SAM 2
BLACK FAULT
CENTRAL FAULT
TOTEM SILICA AREA
ML-95
tetra,mal,az
WEST WALL FAULT
ML-92
GLACIER
SNOW
ML-93
cpy
BLACK FAULT
FLEECE BOWL ZONE
FB-85-18
TOTEM
TOTEM 2
BEAR 4
BEAR
BEAR 3
GLACIER
TR-85-3
HELEN
TROY RIDGE
WEST WALL FAULT
ML-81
BEAR MAIN ZONE
BEAR-85-19
BEAR-85-7
BEAR FAULT
DEBRIS FLOW (Landslide)
CORE STORAGE
CAMP
DOCK
BEAR
BEAR 1
BEAR 2
MUDDY LAKE
(Bearskin Lake) Elev. approx. 960m
TOTE RD.
To Telegraph Cr.
Approx. 120 Km
LEGEND
LATE TERTIARY
8 BASALT DYKE
UNKNOWN AGE
7 AUGITE PORPHYRY DYKE
6 INTERMEDIATE DYKE
LATE TRIASSIC TO EARLY JURASSIC
5 FOLIATED DIORITE
PRE-UPPER TRIASSIC
4 TUFF
4a IRON CARBONATE ALTERED TUFF
PERMIAN
3 FELSIC PHYLLITE
2 LIMESTONE
2a DOLOMITE
2b DOLOMITIZED LIMESTONE
2c SILICIFIED DOLOMITE
2d SILICIFIED LIMESTONE
2e CARBONACEOUS LIMY SEDIMENT
UNKNOWN AGE
1 GABBRO MICROGABBRO

Figure 2-13-1. Location map showing age dates (▲) and chemical analyses (■), Golden Bear property.

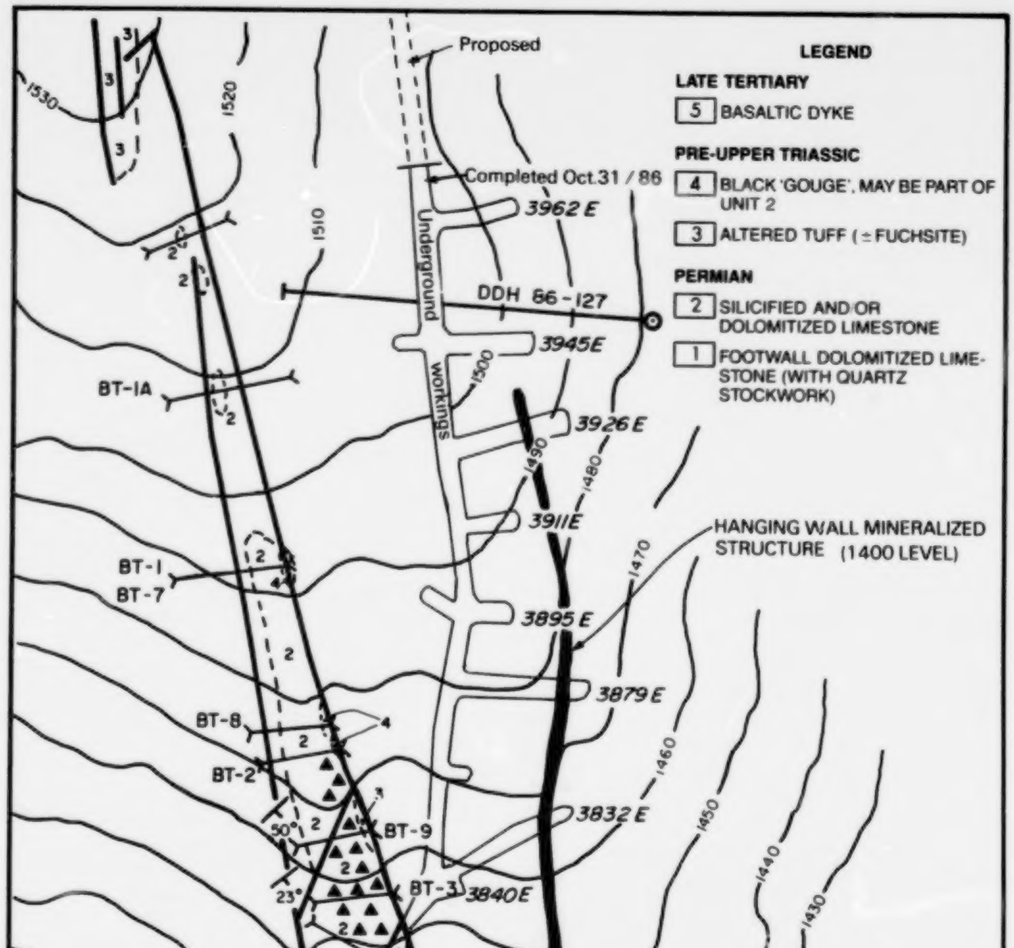
Proposed
LEGEND
LATE TERTIARY
5 BASALTIC DYKE
PRE-UPPER TRIASSIC
4 BLACK 'GOUGE', MAY BE PART OF UNIT 2
3 ALTERED TUFF (± FUCHSITE)
PERMIAN
2 SILICIFIED AND/OR DOLOMITIZED LIMESTONE
1 FOOTWALL DOLOMITIZED LIME-STONE (WITH QUARTZ STOCKWORK)
1530
1520
1510
Completed Oct.31 / 86
3962 E
Underground workings
DDH 86-127
3945E
1500
BT-1A
3926 E
1490
1480
3911E
HANGING WALL MINERALIZED STRUCTURE (1400 LEVEL)
1470
BT-1
BT-7
3895 E
3879 E
BT-8
BT-2
1460
3832 E
1450
50°
BT-9
1440
23°
BT-3
3840E
1430
BT-4
BT-10
3789W
3809 E
80°
BT-5
BT-11
3784 E
1420
1410
BT-12
1400
1400 m PORTAL
N
0
METRES
50
65°

Figure 2-13-2. Geological plan of Bear Main zone, Golden Bear deposit.

It appears that up to 55 per cent of the gold may occur in the hangingwall foliated tuffs and 45 per cent in the hangingwall breccia, with a small amount in silicified limestones and dolomites of the zone (J. Franzen, personal communication, 1986).

AGE DATING

Five samples collected during the 1985 field season for age dating were run in October 1986 (*see* Figure 2-13-1 for sample locations). The results are shown in Table 2-13-1 together with two previously reported dates from the area.

Four samples of drill core were selected from the three zones of interest, Bear, Fleece Bowl and Totem Silica. Sericite was analysed, and is assumed to represent the age of alteration and perhaps mineralization. An additional sample was taken from a relatively fresh hornblende porphyry dyke, which lies along the fault zone trace at the "2 oz. Notch" showing, approximately 10 kilometres northwest of the Bear Main zone. Elsewhere this dyke is mineralized.

The results are shown in Table 2-13-1. They indicate a period of hydrothermal alteration (± mineralization?) extending over a period of at least 30 million years (ages of 174 to 204 million years) with a possible additional 20 million years as suggested by the young, late-stage mineralized dyke from the "2 oz. Notch" showing. The main period of alteration (mineralization?) is suspected to have occurred at 200 ± 7 million years (Early Jurassic).

The age of mineralization appears to be significant with respect to the timing of mineralization elsewhere in British Columbia, particularly in the northwestern part of the province in the Toodoggone and Stewart gold districts. A strong positive correlation exists between the ages of volcanic and intrusive events, alteration, and mineralization.

CHEMICAL ANALYSES

Four grab samples were collected in 1985 for complete major oxide analyses. The results are shown in Table 2-13-2. The mafic units, gabbro and "greenstone", are alkali basalts and basalts respectively. The locations of the samples are indicated in Figure 2-13-1. A description of rock types on the property is included in *Geological Fieldwork, 1985* (Schroeter, 1986).

TABLE 2-13-2.
MAJOR OXIDE ANALYSES, GOLDEN BEAR DEPOSIT

	1	2	3	4
SiO_2	47.29	45.07	47.44	67.44
TiO_2	1.16	2.16	0.58	<0.02
Al_2O_3	14.30	13.86	13.10	0.07
Fe_2O_3	15.39	12.88	12.33	0.13
MnO	0.228	0.15	0.209	0.11
MgO	6.12	7.54	8.93	0.15
CaO	9.66	9.83	12.81	18.02
Na_2O	2.87	2.87	1.84	<0.01
K_2O	1.07	0.69	0.60	0.02
P_2O_5	0.27	0.36	0.15	0.08
LOI	1.77	5.13	3.05	18.97
Total	**100.10**	**100.50**	**101.00**	**104.57**

Key to Analyses:

Lab No.	Field No.	Field Description	Area (Zone)	Classification
1-30915	TR-85-3	Gabbro	Troy Ridge	Alkali basalt
2-30916	BEAR-85-7	Basalt dyke	Bear Main	Basalt-alkali basalt
3-30917	BEAR-85-19	"Typical greenstone"	Bear Main	Basalt
4-30918	FB-85-18	Silicified carbonate	Fleece Bowl	Silicified limestone

ORE DEPOSITIONAL MODEL

As suggested earlier (Schroeter, 1985, 1986), the Golden Bear deposit and other precious metal-bearing deposits in the region are postulated to be vein-type with epithermal characteristics. Evidence to date suggests that as the mineralizing solutions ascended the fault zone between carbonate rocks and volcanic tuffs they reached a point, termed a "roll" by J. Franzen (personal communication, 1986), where extensive tectonic brecciation, silicification and carbonatization took place in the host limestones, dolomites and tuffs above this flexure (Figure 2-13-3). In the footwall, carbonate rocks (dolomites?) show a diffuse pattern of alteration over distances of 1 to 2 metres, producting a texture referred to locally as "rind" rock (J. Franzen, personal communication, 1986). Clast-supported breccia fragments with beige to orange limonitic reaction rims in a dark grey sulphide-rich matrix, and/or carbonate-filled fractures are typical textures seen in this rock.

In the hangingwall a silicic mineralized breccia developed (Plate 2-13-2) with a higher grade zone of mineralized volcanic tuff lying above it. Locally the tufts are altered to a listwanitic quartz-iron carbonate-pyrite-fuchsite assemblage (Schroeter, 1986, page 181).

Regionally some stratigraphic units, particularly limestones, have been preferentially brecciated and silicified, especially adjacent to fault zones. The apparent selective replacement of these horizons has produced stratabound mineralized zones. The permeability and/or porosity of these rock units may have been important factors in determining depositional sites for the ascending mineralizing solutions. Locally, within the Bear Main zone, much more detailed sampling will be required to test this hypothesis.

A possible genetic association with an early Jurassic event is suggested by recent age dates (this report). In addition, a mineralized intrusive feldspar porphyry dyke (F1 dyke) in the Fleece Bowl zone was intersected by diamond drilling; unfortunately an attempt to date it was unsuccessful. Intrusive activity, alteration and mineralization along the major regional fault (Ophir lineament) is postulated to have occurred over a 50-million-year time span (that is, 156 to 206 million years).

PROJECT WORK

Work in 1986 consisted of:

(1) 850 metres of underground development; including 325 metres of drifting, 375 metres of crosscutting and a 150-metre raise;
(2) 1457 metres of surface diamond drilling;
(3) 1000 metres of underground drilling;
(4) Examination of two possible all-weather access routes to connect the property with the Telegraph Creek road (Highway 114) either at Telegraph Creek, a distance of approximately 120 kilometres, or at the Tahltan River crossing, a distance of approximately 140 kilometres;
(5) Minesite and road environmental studies;
(6) Minesite and waste management geotechnical studies;
(7) Metallurgical bulk sampling and pilot scale testing;
(8) Initiation of a final feasibility study.

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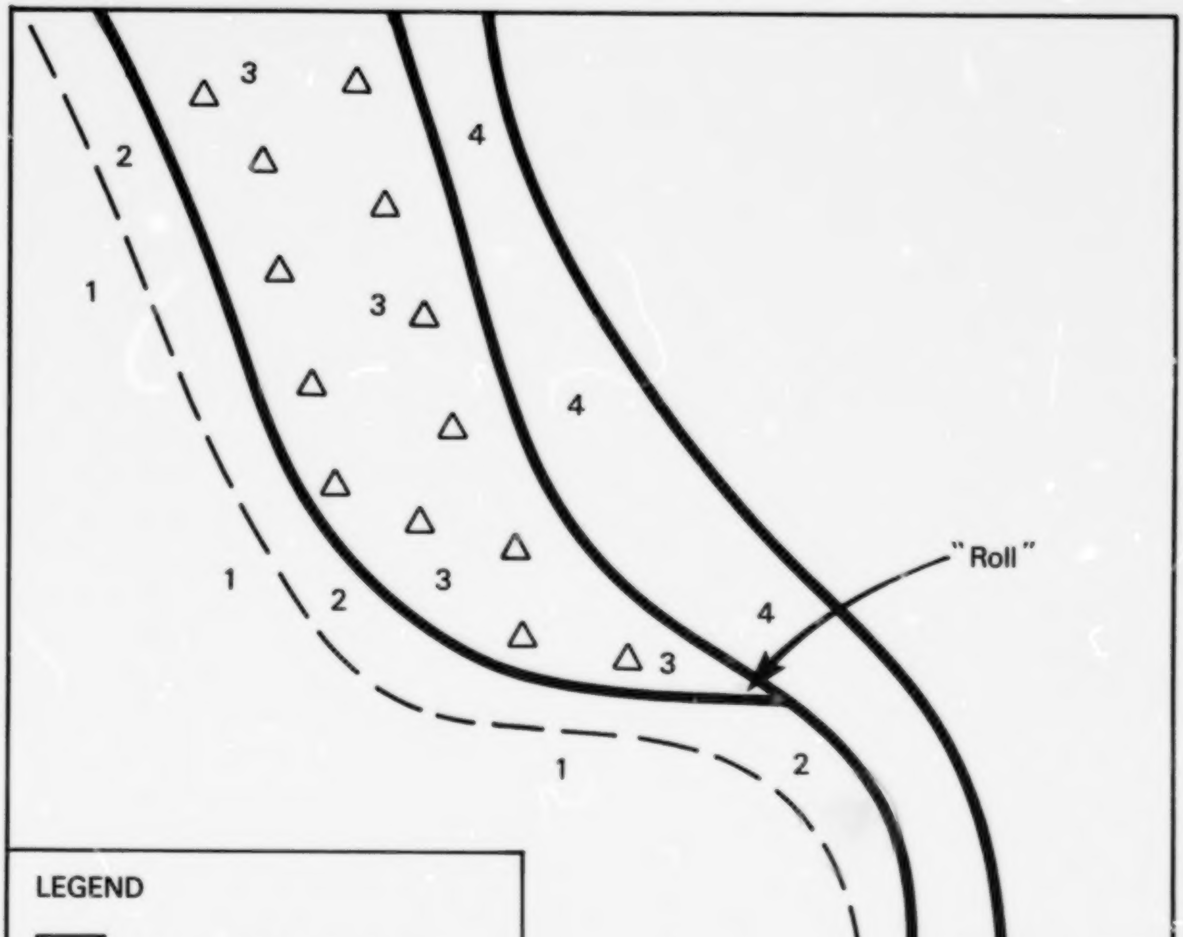
3
4
2
1
3
4
1
2
3
4
3
"Roll"
1
2
4
1
LEGEND
4 Hangingwall volcanic tuff
3 Silicic hanging wall breccia
2 'Rind' rock, silicified dolmite / limestone
1 Carbonate unit, minor dolomite ± silicification
SYMBOLS
Brecciation
Fault
Diffuse boundary of rind rock
50
metres
Scale
0
0
metres
10
Ascending hydrothermal solutions (Depth unknown)
INTRUSIVE SOURCE

Figure 2-13-3. Schematic representation of ore genesis and emplacement, Bear Main zone, Golden Bear deposit.

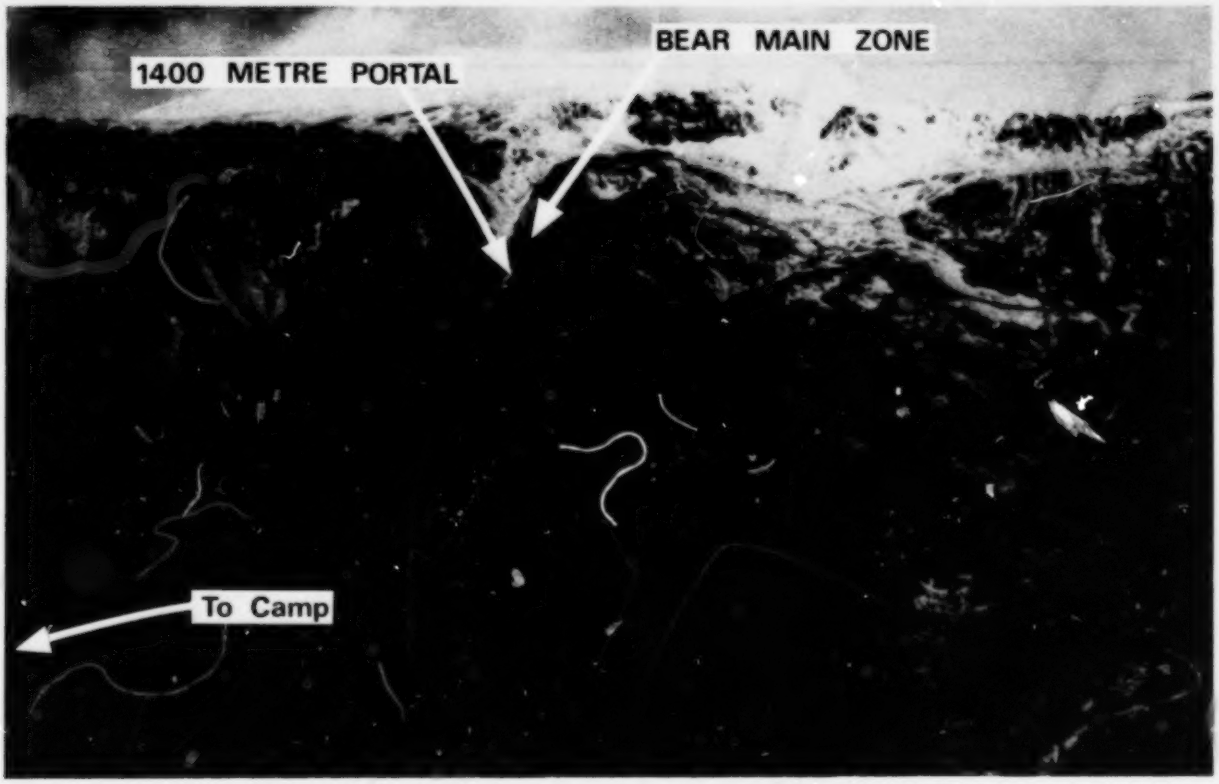
BEAR MAIN ZONE
1400 METRE PORTAL
To Camp

Plate 2-13-1. Looking northwesterly over Bear Main zone, Golden Bear deposit.

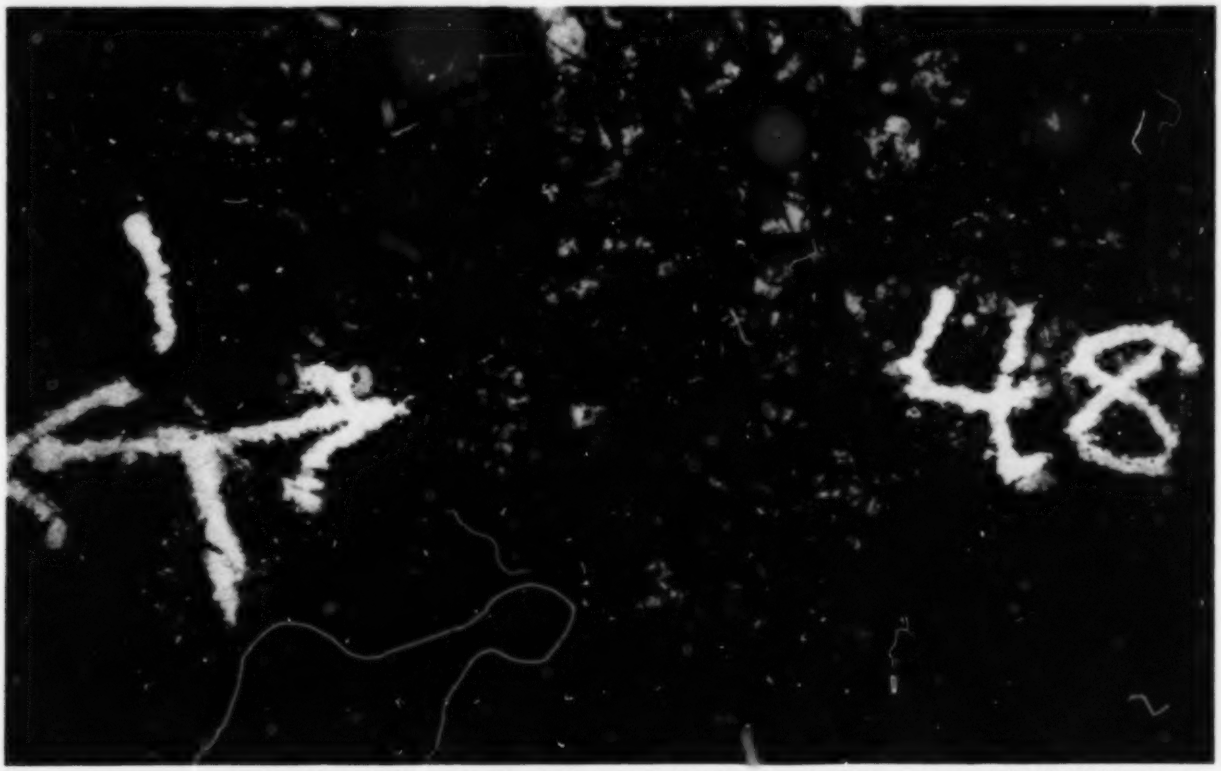

Plate 2-13-2. Hangingwall mineralized silicic breccia, Bear Main zone, Golden Bear deposit. Fragments are mainly silicified limestone; matrix is mainly fine-grained pyrite and a minor mixture of very fine-grained rock fragments.

lumbia Ministry of Energy, Mines and Petroleum Resources for mineral separations and potassium analyses, and Joe Harakal (The University of British Columbia) for his speedy and precise argon determinations and age calculations. The writer also has benefited from discussions with Jeff Franzen and Bob Dickinson of North American Metals and Godfrey Walton of Chevron Minerals. Logistical support and camp hospitality by North American Metals are gratefully acknowledged.

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TOODOGGONE RIVER AREA
(94E)

By T. G. Schroeter and D. V. Lefebure

INTRODUCTION

During the summer of 1986, the writers visited the Toodoggone gold-silver camp on three occasions in order to keep abreast of ongoing exploration activities. In excess of $3.5 million was spent by companies in the Toodoggone area in 1986, down from the record figure of $6 million last year. The drop in expenditures is principally due to the fact that Serem Inc. and St. Joe Canada Ltd. did not carry out major programs this year.

Positive exploration results have been obtained this summer, particularly on the Baker mine, Al and Mets properties, and a number of the properties in the area have indicated mineral reserves (Table 2-14-1).

ACCESS

Access into the area continued to be by fixed-wing aircraft from Smithers to the Sturdee airstrip (approximately 300 kilometres). Road access exists from the Sturdee airstrip to the Baker, Lawyers and Silver Pond properties. All other properties can be reached on foot or by helicopter or tractor (Figure 2-14-1).

A provincial government loan to Serem Inc., to upgrade and extend the Omineca Resource road to the Toodoggone, has been approved in the amount of $4.5 million. The loan is conditional upon Serem Inc. making a production decision. The company had not made this decision as of October 1986.

REGIONAL GEOLOGY

The regional geology of the Toodoggone area is described in several publications including Barr (1978), Schroeter (1981 to1985), Panteleyev (1982 to 1984), Diakow (1983 to 1985), Forster (1984) and Schroeter *et al.* (1986). Other references include Preliminary Map No. 61, Geology of the Toodoggone Area, NTS 94E (Diakow *et al.*, 1985) and numerous company assessment reports on file with the British Columbia Ministry of Energy, Mines and Petroleum Resources.

CLAIM STATUS

An unofficial status of claim holdings in the Toodoggone River area is shown in Figure 2-14-1. Current operators are listed in Table 2-14-2.

PROPERTY UPDATES

Brief visits were made to most of the active properties in the area and only the highlights of ongong exploration activity are described in this article. The pertinent data on the major properties are summarized in Table 2-14-1.

BAKER MINE (CHAPELLE, MI 94E-026) — MULTINATIONAL RESOURCES INC.

During 1986, Multinational Resources Inc., working under an option agreement with Du Pont of Canada Exploration Ltd., drilled 1920 metres in 23 diamond-drill holes. All the drilling was on the B vein to the northeast of the Baker mine, except for one hole drilled on the A vein, in an unsuccessful attempt to pick up an extension of the Baker mine at depth (Plate 2-14-1). The B vein does not outcrop, but its position is marked by a surface gossan underlain by altered volcanic rock with very minor quartz veinlets. The North Quartz zone, where erratic gold values have been intersected in drill holes, lies along strike to the northeast of the B vein.

Drilling on the B vein has delineated a steeply dipping white quartz vein with minor pyrite, chalcopyrite and sphalerite averaging 2.5 to 3 metres in width and hosted by altered Takla Group volcanic rocks. The mineralized zone, which has now been traced over a strike length in excess of 90 metres and to a depth of 90 metres, appears to be a northeast-raking shoot in the plane of the vein. Late season drill results include:

Hole No.		Gold g/tonne	Silver g/tonne	True Width (metres)
86-23		41.14	102.9	3.44
	and	48.0	27.43	2.3
86-33		58.35	729	3.66
	incl.	92.57	1114.3	3

Source: The Northern Miner, November 3, 1986.

LAWYERS (MI 94E-066) — SEREM INC.

During 1986, Serem Inc. was basically in a "holding pattern" pending completion of financial arrangements to bring the property into production at a rate of 500 tonnes per day. The deposit contains estimated reserves of 941 000 tonnes grading 7.2 grams of gold and 260 grams of silver per tonne. Serem completed only minor clean-up and assessment work in 1986.

AL — ENERGEX MINERALS LTD. —
THESIS III (MI 94E-091)
BV (MI 94E-091)
BONANZA RIDGE (MI 94E-079)

Energex Minerals Ltd. completed 83 diamond-drill holes totalling 3683 metres as well as gradient-array, multipole induced polarization surveys, 4000 lineal metres of backhoe trenching in 141 trenches, soil sampling and boulder prospecting. The drilling was carried out on the Thesis III, Thesis II, BV and Bonanza Ridge zones to better define the previously estimated open-pit mineral inventory estimated at 239 550 tonnes grading 8.51 grams of gold per tonne. Exploration costs to the end of October were estimated at $1.9 million with a further $350 000 to be spent by the end of February 1987 for feasibility studies, environmental work, and other advanced studies.

The Thesis III zone was the the most active area on the Al property; a total of 29 holes was drilled in addition to channel sampling and test mining on the surface outcrop of the mineralized zone. Approximately 12 000 grams of gold have been recovered from Thesis III zone ore processed through a 6-tonne-per-day pilot mill. Head grades ranged from 34 grams per tonne up to a maximum of 130 grams per tonne. Energex Minerals Ltd. is pleased with the results and propose building a minimum 45 to 50-tonne-per-day mill on the site in 1987.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

TABLE 2-14-1.
MAJOR EXPLORATION PROPERTIES IN THE TOODOGGONE GOLD CAMP

PROPERTY NAME	OPERATOR	YEAR OF DISCOVERY (New Discovery)	DIMENSIONS (Drill Tested) Length × Width × Depth (Min.) (m) (m) (m)	MINERALOGY		RESERVES (tonnes @ g/tonne)
				ORE	GANGUE	
BAKER (ex-Chapelle)	Multinational Resources Inc.	1969	435 × 0.5 to 9 × 150	Electrum, argentite, with minor chalcopyrite, sphalerite, pyrite, galena, bornite, polybasite, stromeyerite	Quartz, chlorite, calcite and trace flourite	— Produced 1 168 175 g Au (34072 oz.) and 23 084 969 Ag (673326 oz.) from 77 500 tonnes (85500 tons), 1980–1983
	(ex-DuPont of Canada Exploration Ltd.)	(1986)				— Active exploration on 'B' Vein. Possible 50 000 tonnes outlined
LAWYERS AGB Zone Cliff Creek Zone Duke's Ridge Zone	Serem Inc.	1973	500 × 60 to 75 × 150 660 × 9 × 250 480 × 5 × 100	Native gold, native silver, electrum, argentite, with minor pyrite, chalcopyrite, sphalerite, galena and chalcocite	Chalcedony, quartz, amethyst, calcite, with minor adularia, hematite, barite, kaolinite, illite, montmorillonite	Total = 941 000 @ 7.2 Au (0.21 oz./ton) and 260 Ag (7.61 oz.) AGB — 50%; Cliff Creek — 45%; Duke's Ridge — 5%. Note: 20% of known surface strike-lengths drilled
AL Thesis III Zone BV Zone Bonanza-Ridge Zone	Energex Minerals Ltd.	1981	200 × 5 to 30 × 75 500 × 5 × 50 300 × 3 5 × 35	Native gold with minor pyrite, tetrahedrite, electrum, argentite, chalcopyrite, galena and sphalerite	Quartz, barite, calcite with minor alunite, illite, hematite, sericite	Thesis III 121 624 @ 8.49 Au BV 117 926 @ 8.54 Au Total 239 550 @ 8.51 Au (open pittable) 1986: Pilot mill @ 6 tpd. ~12 000 g produced
SHAS Creek Zone	International Shasta Resources Inc.	1982	370 × 5 to 23 × 100	Native silver, electrum, argentite, with minor native gold, galena, chalcopyrite and sphalerite	Chalcedony, quartz with minor barite	2 176 800 @ 2.7 Au (0.079 oz./ton) incl. 471 640 @ 5.9 Au (0.172 oz/ton)
METS	Manson Creek Resources Ltd.	1981	125 × 5 to 9 × 60	Native gold, pyrite	Quartz, barite, hematite	OPEN, includes 13m @ 18 Au
SILVER POND West Zone Cloud Creek Zone	St. Joe Canada Inc.	1985		Electrum, pyrite, argentite, with minor chalcopyrite and tetrahedrite	Quartz, kaolinite, alunite	OPEN, includes values to 44 Au
JD Vein Zone Gasp Zone Gumbo Zone	Energex Minerals Ltd.	1981	600 × 1 to 4.6 × 50 150 × 20 × ? 400 × 10 × ?	Native gold, native silver, with minor galena, sphalerite, chalcopyrite and pyrite	Quartz, calcite, with minor hematite, barite, and various clays	OPEN, includes 27 210 @ 5.5 Au — Gumbo Zone (open pittable)
METSANTAN — Several Zones	Lacana Mining Corp.	1981	550 × 4 to 7 × 100 (Ridge Zone)	Chalcopyrite, galena, pyrite, sphalerite and trace polybasite	Quartz, amethyst, sericite, kaolinite, barite	OPEN, includes 4m @ 7.54 Au and 20m @ 6.3 Au
MOOSEHORN	Cyprus Metals (Canada) Ltd.	1981	670 × 1 to 5 × ?	Pyrite + argentite?	Amethyst, quartz, calcite	OPEN, include assays to 16.1 Au
GOLDEN LION	Newmont Exploration of Canada Ltd.	1981	200 × 2 to 10 × 20	Galena, sphalerite, with minor pyrite, chalcopyrite, acanthite and linarite	Quartz, barite, calcite, hematite	OPEN, includes assays to 35 Au and 7540 Ag
GOLDEN NEIGHBOUR	Lacana Mining Corp.	1980	460 × 3 to 130 × ? (geochemical anomaly)	Pyrite, argentite, sphalerite, galena, molybdenite	Quartz, kaolinite	OPEN
GOLDEN STRANGER	Western Horizons Resources Ltd.	1983	460 × 3 to 45 × ? (trenched)	Pyrite, chalcopyrite, galena, sphalerite	Amethyst, quartz	OPEN, includes 4m @ 11.7 Au (trench)

Plate 2-14-1. Looking north over the Baker mine property. Camp and mill in foreground; open cut and underground workings on A vein above; possible extension of B vein located along strike to the northesat, across small creek.

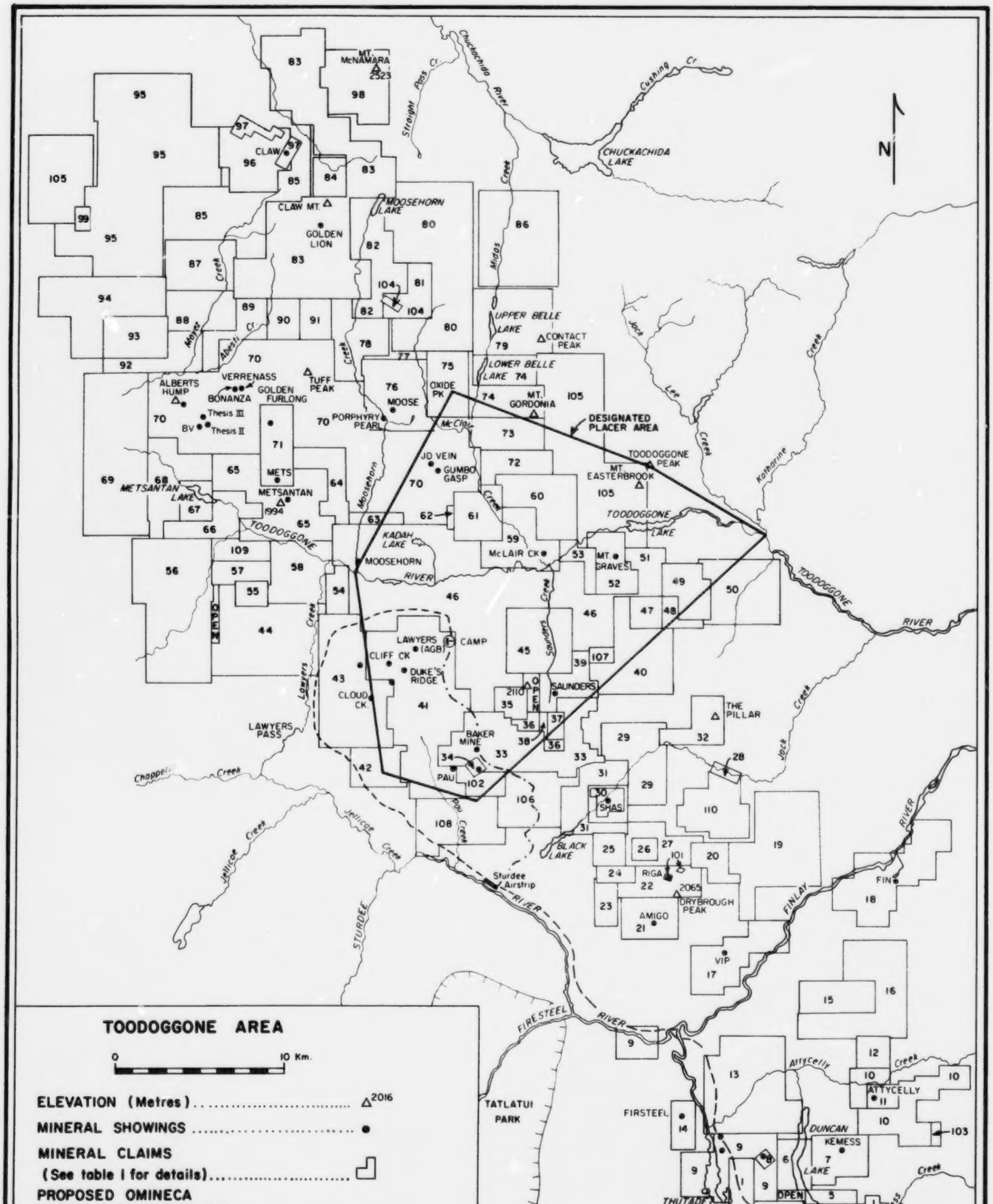
Airborne magnetic data, geological mapping, trenching and drilling indicate that the Thesis III, Thesis II, BV and Bonanza Ridge mineralized zones can be traced for 3 to 6 kilometres along three separate north to northwest-trending fault systems. The Thesis II zone is now considered by company geologists to be the southeastern extension of the Thesis III zone with erratic mineralization extending over a strike length of 500 metres, only 20 per cent of the structure defined by airborne magnetometer survey (Plate 2-14-2). Energex maps alteration facies rather than primary lithologies because the biotite hornblende phyric ash flow is so strongly altered.

On the high-grade Verrenass area of the Bonanza Ridge zone, drilling intersected additional mineralization containing visible gold. Further trenching along strike to the south encountered characteristic silicification. Drilling on the BV zone confirmed continuity of the mineralization over a 6 to 9-metre width and containing 10.3 to 17.1 grams of gold per tonne. Several other geologically favourable zones, including the Golden Furlong (MI 94E-080), require further testing. Highlights from drilling include:

Zone		Hole No.	Width (metres)	Gold g/tonne
Bonanza Extension		A86-67	3.0	71
	incl.		1.5	139
		A86-69	6.2	5.14
	incl.		0.5	18.17
BV		A86-77	7.53	22.63
	incl.		4.54	34.98
		A86-80	8.8	25.56
	incl.		3.2	59.33
Thesis III		A86-54	5	138.5
	incl.		1	529.4
		A86-44	6.9	27.8
	incl.		1	160.8

Source: George Cross Newsletters, September 3, 1986 and November 12, 1986.

Preliminary ore reserve calculations by Energex suggest potential for open-pit deposits in the order of 3 million tonnes grading better than 3.4 grams of gold per tonne.



TOODOGGONE AREA
0
10 Km.
ELEVATION (Metres) .... △2016
MINERAL SHOWINGS .... ●
MINERAL CLAIMS
(See table I for details) ....
PROPOSED OMINECA
MINING ROAD ETXENSION ....
EXISTING ROAD ACCESS ....
N
MT. McNAMARA 2323
CLAW MT.
CLAW
GOLDEN LION
MOOSEHORN LAKE
CHUCKACHIDA LAKE
Chuckachida River
Cushing Cr
Straight Pass Cr
Midas Creek
UPPER BELLE LAKE
LOWER BELLE LAKE
CONTACT PEAK
OXIDE PK
MT. GORDONIA
DESIGNATED PLACER AREA
TOODOGGONE PEAK
MT. EASTERBROOK
TOODOGGONE LAKE
TOODOGGONE RIVER
ALBERTS HUMP
VERRENASS
BONANZA
GOLDEN FURLONG
TUFF PEAK
Thesis III
Thesis II
BV
PORPHYRY PEARL
MOOSE
METS
METSANTAN
1994
METSANTAN LAKE
JD VEIN
GUMBO GASP
KADAH LAKE
MOOSEHORN
MOOSEHORN RIVER
McLAIR CK
MT. GRAVES
LAWYERS (AGB)
CAMP
CLIFF CK
DUKE'S RIDGE
CLOUD CK.
LAWYERS PASS
2110
OPEN
SAUNDERS
BAKER MINE
PAU
THE PILLAR
SHAS
BLACK LAKE
RIGA
2065
DRYBROUGH PEAK
AMIGO
VIP
FIN
Sturdee Airstrip
STURDEE RIVER
FIRESTEEL RIVER
FINLAY RIVER
TATLATUI PARK
FIRSTEEL
DUNCAN LAKE
KEMESS
ATTYCELLY
Attycelly Creek
Kemess Creek
THUTADE LAKE
RAT
OPEN
Jack Creek
Lee Creek
Katharine Creek
Chappell Creek
Jellicoe Creek
Abesti Cr
Moyez Creek
Lawyers Creek
Saunders Creek
Pau Creek
McClair

Figure 2-14-1. Claims in the Toodoggone River area, June 1986.

TABLE 2-14-2.
TOODOGGONE RIVER AREA MINERAL PROPERTIES

NO.	CLAIMS	MINERAL INVENTORY NUMBER (94E)	OPERATOR
1	RON 1-11	13, 14, 15	Pacific Ridge Res.
2	DU, DU 2	—	Pacific Ridge Res.
3	RAT	25	Cominco
4	TUT 1, 2	—	Univex Mining
5	DU 1, 2	—	Pacific Ridge Res.
6	DUNCAN 1-4	—	Asitka Res.
7	NEW KEMESS 1, 2	21	Kennco
8	CROWN-GRANTED CLAIMS	12	Cominco
9	LAKE 1-15	—	Pacific Ridge Res.
10	KEM 1-9	—	Inca Res.
11	AUDREY WEST, AUDREY EAST	22	ABM Mining Group
12	AWESOME	81	Inca Res.
13	ARK 1-7	—	Ark Energy
14	FIRESTEEL	2	SEREM
15	WRICH 1-3	82	SEREM
16	RICH 1-5	—	Golden Rule Res.
17	GRACE 1-5	48	Asitka Res.
18	FIN 1-9	16	B. Pearson
19	JOCK 4, 6-12	—	Golden Rule Res.
20	GOLDEN RING, GOLDEN RING 2	—	Newmont Expl.
21	STAR, PULL, SUN	58	SEREM
22	PARADISE 3, 4	—	Phillip Res.
23	DALE	—	M. Bell
24	LEGHORN	—	Energex
25	JERRY	—	Phillip Res.
26	DAWN	—	Newmont Expl.
27	SHASTEX, PARADISE 2	—	Alexim
28	BRENDA 1-8	8	Canasil
29	JK 1-5	39	Golden Rule Res.
30	SHAS, SHA 1-2	50	International Shasta
31	SHASTA 3-5, SILVERREEF 3	—	International Shasta
32	ATLAS, HERCULES	42, 83	SEREM
33	CHAPPELLE	26, 71	Multinational Res.
34	CROWN-GRANTED CLAIMS	27	O. McDonald
35	PEL	—	Multinational Res.
36	XT 1, 3	—	W. McClay
37	DAVE PRICE	—	Western Horizons
38	XT 2	—	Golden Rule Res.
39	GOLDEN NEIGHBOUR 1-4	37	Lacana
40	IAN, ADRIAN, PAUL, OTTO	—	Rhyolite Res.
41	NEW LAWYERS 1-4, LAW 1-3, BREEZE, ROAD 1-3, PERRY 1, 2, MASON 1, 2, GTW 1-3, ATTORNEY 2	66, 67, 74, 72, 73	SEREM
42	ATTORNEY 1, 2	—	W. McClay
43	SILVER POND, ASAP, SILVER SUN, SILVER CLOUD 1-3, SILVER CREEK	69, 75	St. Joe
44	PC 1-4, MM 1-4	—	Tanker Oil and Gas
45	SAUNDERS	40	Golden Rule Res.
46	GWP 1, 10-30, 34, 40, 41, 43, 200	86	Cyprus Metals
47	DEBRA LYNN	—	Kelley-Kerr Energy
48	MARKER	28	Kelley-Kerr Energy
49	SAMMY, SUN	89	Newmont Expl.
50	KNIGHT, KEVIN, BISHOP, CASTLE	—	Hi-Tec Res.
51	GRAVY II, IV	—	Hemlo Expl.
52	GRAVES 1, 2	7, 87	Miramar
53	GRAVY I, II, TODD	—	Kelley-Kerr Energy
54	KODAH 1-2	68	SEREM
55	GOLDEN STRANGER, GOLDEN STRANGER 2	76	Western Horizons
56	LASSIE 1-4, LADD 1-4	—	Alexim
57	SB 3, 4	—	S. Young
58	LAINEY 1-4	—	Gold Texas Res.
59	MAC III, HYFLY I, II	1	Black Diamond
60	MAC I, II, IV	—	Goldbrae Dev. Ltd.
61	BELLE 1, 2, 4	—	Manson Creek Res.
62	BIG LODE	—	Alexim
63	KEY	—	Hi-Tec Res.
64	LEXIM 1-3, GWP 42	—	Mandusa Res.
65	METSANTAN 1-9	64	Lacana
66	SY 2-4	—	A. L. Constantine
67	DISCOVERY 4	—	Black Diamond Res.
68	DISCOVERY 1-3	—	Duke Minerals
69	INDIAN GOLD 1-4, TOODOGGONE 1-4	—	Alexim
70	AL 1-8, BERT, ERNIE, WINKLE, BULL, CHUTE, SURPRISE GEROME, CALF MOOSE, ANTOINE, LOUIS, TOUR COW MOOSE, STURDEE, JM, JS, KADAH 1-2, BIG BIRD, GAS 1, JR, JB, JD	66, 65, 80, 78, 85, 84, 79, 91, 32	Energex
71	METS 1, 2	—	Manson Creek Res.
72	PEREGRINE, FALCON A	—	Multinational Res.
73	JOANNA III, JOANNA IV	—	International Damascus
74	JOANNA I, II	36	Armour Res.
75	AMETHYST, KIDVIEW	—	Geostar
76	SCREE 1-3, MOOSE 1-3, BULLMOOSE, GAS 2	31	New Ridge Res.
77	OXIDE I	—	Alexim
78	HORN 1-5	20	Norman Res.
79	LAKE I-IV, MAGIC I, II	23	PMA Technologies Inc.
80	CAT 1-4, MID 1-3, BELL 1-3	59	A. L. Constantine
81	GORD DAVIES, GORDON DAVIES	53	Lacana
82	HORN 1-4, AS 1-3	—	Gold Texas
83	GUARD, LYNX 1-8, GOLDEN LION 1-11, HUMP 1-2	77, 19	Newmont Expl.
84	SPAR MOUNTAIN	—	C. Kowall
85	PAW, PIKA, CAL 1, YET 1 SUET, GACHO	—	Hi-Tec Res.
86	ORO I, II, URUS I-IV	—	Hi-Tec Res.
87	RANGER 1-4	—	Cusac Industries
88	MOYEZ 1, 2, 4	—	Geostar
89	SPIKE, WOLF I	—	Hi-Tec Res.
90	WOLF II	—	Texpez Oil and Gas
91	WOLF III	—	Skeena Res.
92	CHUCK 1, 2	—	Miramar
93	MOYTAN I, II	—	Yukon Gold Placers, Geostar
94	ADOOG 1-5, STIK 1-4	—	Delaware Res., Golden Rule Miramar
95	GACHO 1-3, WILDCAT 1-3, HEAVY METAL 1-8, SHEEP ROCK 1, 2	54, 62	Dayton Dev. Corp.
96	COPPERKING 1-5 NAMERA IV	—	Sutton Res., Redfern Res.
97	CLAW	46	Umex
98	WOLVERINE I-IV	—	Hi-Tec Res.
99	DAR	90	Newmont Expl.
100	SILVER REEF	—	Newmont Expl.
101	RN	3	Windarra
102	CASTLE MT. 1	—	Energex, Caprock
103	MESS 4	70	SEREM
104	HAR	53	Kennco Expl.
105	MET 1-2, GORD 1-4, MUL 1-4	—	M. Bell
106	BLACK	—	Hi-Tec Res.
107	ARGUS 2 plus?	—	Rhyolite Res.
108	HECKLE, JECKLE, TITAN	—	M. Bell
109	SB 1, 2	—	P. Crook
110	JOCKY 1-5	—	Golden Rule

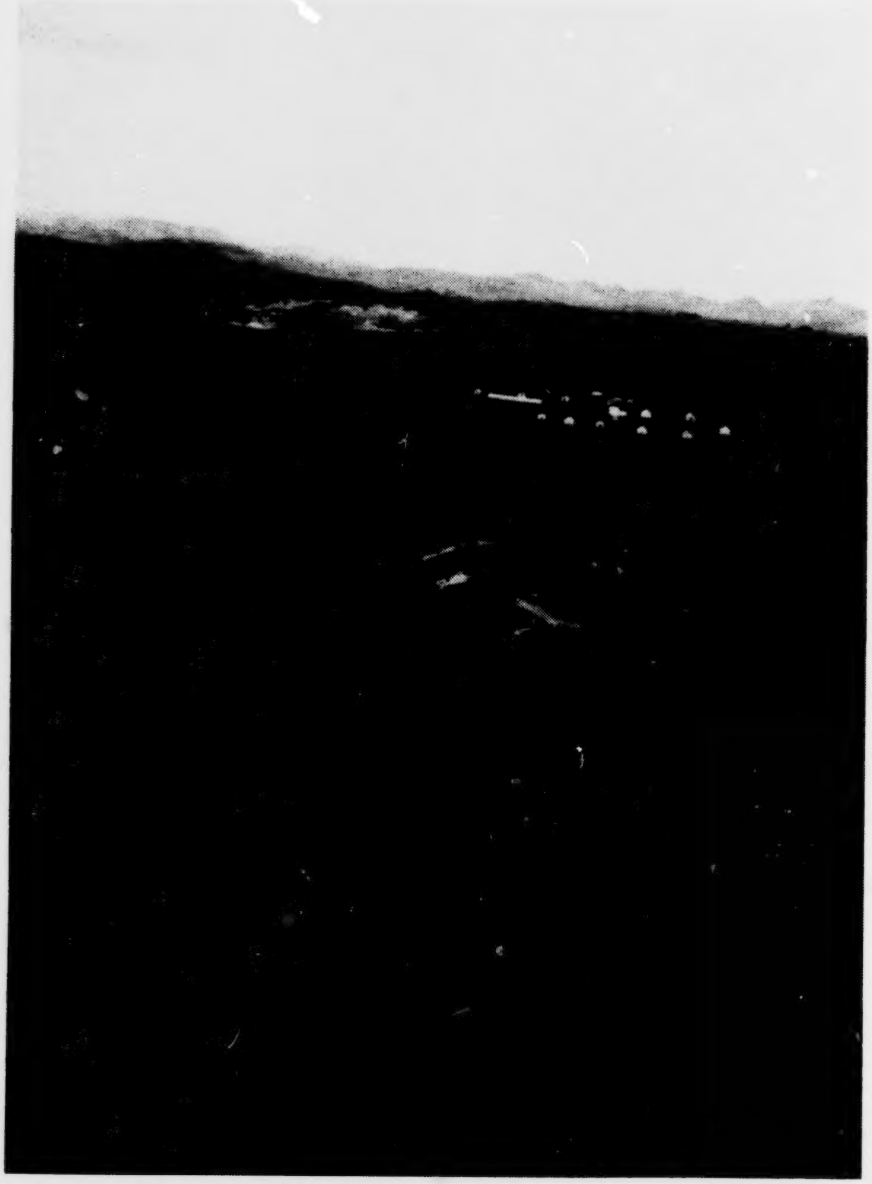


Plate 2-14-2. Looking northwest over the Thesis II (lower workings) and Thesis III (upper workings) zones, Al property. Energex camp to right. Note small mill set up on Thesis III zone.

METS (MI 94E-093) — MANSON CREEK RESOURCES LTD.

A total of 20 diamond-drill holes, totalling 1653 metres, was drilled by Manson Creek Resources Ltd. on the A zone under an option agreement with Golden Rule Resources Ltd. Backhoe trenching, surface sampling and mapping were also completed in 1986. On surface the gold-bearing structure has been traced for 2400 metres (Plate 2-14-3). The A zone consists of a quartz-barite breccia with flanking clay-altered (dickite?) Toodoggone volcanic rocks which are orange, pink or purple quartz-eye "andesite" porphyries. A similar lithology is found at the Cloud Creek showing (Silver Pond), Golden Stranger property, and AGB zone (Lawyers).

The mineralization is predominantly quartz and barite (locally coarsely bladed) with minor fine-grained galena, native gold and calcite. The A zone has been traced by drilling for a strike length of 150 metres and to a depth of 90 metres, with a true width of 5 to 10 metres. The vein strikes 340 degrees and dips 80 to 90 degrees to the west (Figure 2-14-2). An easterly trending fault bounds the zone to the north. Highlights from the drilling include:

Plate 2-14-3. Looking southeast over the Mets property. A zone traced by drilling occurs near the top of Metsantan Mountain, immediately left of the large patch of snow.

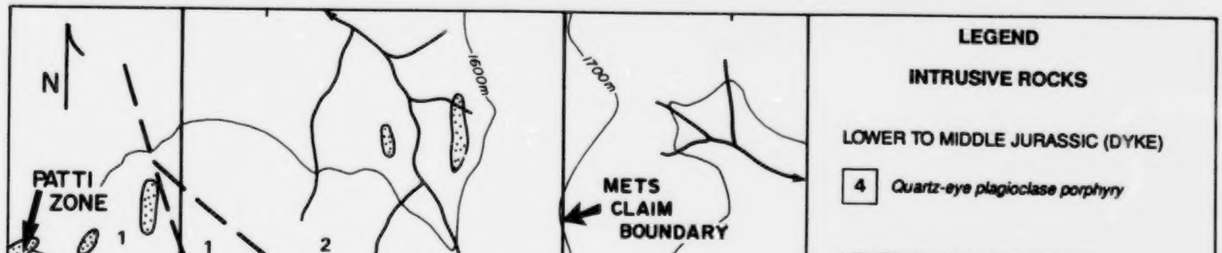

N
PATTI ZONE
METS CLAIM BOUNDARY
METS ('A' ZONE)
93
METSANTAN MOUNTAIN 1994m
x64
METSANTAN
1600m
1700m
1800m
1900m
1500m
6367500N
6365000N
600000E
602500E
0
1000
Metres
LEGEND
INTRUSIVE ROCKS
LOWER TO MIDDLE JURASSIC (DYKE)
4 Quartz-eye plagioclase porphyry
LOWER TO MIDDLE JURASSIC
"TOODOGGONE VOLCANICS"
3 TOODOGGONE CRYSTAL ASH TUFFS AND FLOWS
Quartz plagioclase crystal tuff
2 TUFF PEAK FORMATION
Biotite augite hornblende plagioclase porphyry flows and minor volcaniclastics
1 LAWYERS - METSANTAN QUARTZOSE ANDESITE
Quartz pyroxene(?) biotite hornblende plagioclase porphyry flows and tuffs
SYMBOLS
Mineral prospect (Mineral Inventory Number), mineral occurrence .... x64, x
Alteration Zones (predominantely silica ± clays) ....
UTM Co-ordinates .... 602500 E

Figure 2-14-2. Sketch map of the geology of the Metsantan Mountain area (modified from Diakow *et al.*, 1985).

Plate 2-14-4. Looking northwest over the Moosehorn prospect. The Cyprus camp is located at tip of antenna. Metsantan Mountain is in the background to upper left.

Plate 2-14-5. Looking west over the Brenda property. Jock Creek to the right, camp in the centre, and main zones of interest in the foreground.

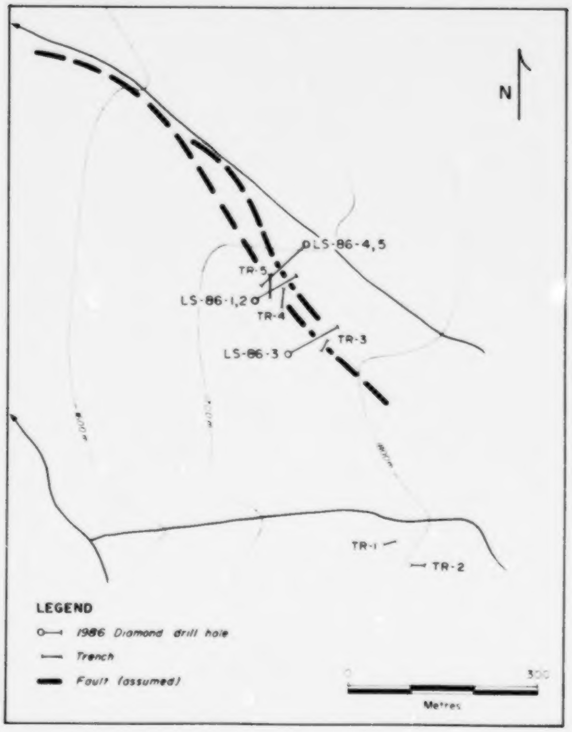

N
LS-86-4,5
TR-5
LS-86-1,2
TR-4
TR-3
LS-86-3
TR-1
TR-2
LEGEND
1986 Diamond drill hole
Trench
Fault (assumed)
0
300
Metres

Figure 2-14-3. Sketch of surface plan, Golden Neighbour property (after company plans).

Plate 2-14-6. Looking over the Golden Stranger prospect. The trenches trace the quartz-amethyst zone. The zone ends near the small lake at the junction of the north-trending structure with a northwest-trending structure. Metsantan Mountain is in the background.

Hole No.		Width (metres)	Gold g/tonne
M-86-8		13	18.1
	incl.	4.6	42.75
M-86-9		6.9	14.2
	incl.	4.6	17.25

Source: George Cross Newsletters, September 8, 1986 and September 30, 1986.

MOOSEHORN (MI 94E-086) — CYPRUS METALS CANADA LTD.

A comprehensive geochemical sampling and geological mapping program was completed over the the Moosehorn property by Cyprus Metals Canada Ltd. in 1986, under an option agreement with Cassidy Resources Ltd. and Imperial Metals Corp. Approximately 4500 soil and 500 stream sediment samples were collected. Twelve diamond-drill holes, totalling 1066.5 metres, were drilled at the western end of the property on the Moosehorn zone, its southern extension and in an area of newly discovered quartz float approximately 1100 metres southwest of the Moosehorn zone (Plate 2-14-4).

The Moosehorn zone crops out as quartz and quartz-amethyst veins cutting altered plagioclase andesite porphyry, part of the Toodoggone volcanic rocks. The dip of the zone is not clearly established and no significant veins were intersected in the three drill holes completed. The drilling on the southern extension of the Moosehorn zone intersected some geochemically anomalous gold values. The most exciting results came from a new mineralized area, with little or no outcrop, approximately 1100 metres southwest of the Moosehorn showing. The zone was found by soil geochemistry which identified a gold-silver anomaly. Quartz float from this zone contains more than 7000 parts per billion (ppb) gold and 175 grams of silver per tonne. Four drill holes intersected geochemically anomalous gold values which appear to define a steep southwest-dipping zone. Further drilling and trenching will be necessary to properly evaluate the large Moosehorn property.

BRENDA (MI 94E-093) — CANASIL RESOURCES INC.

During 1986, Canasil Resources Inc. completed geological mapping, hand trenching, an EMR-16 resistivity survey and limited Winkie diamond drilling on their Brenda claim group located approximately 6 kilometres east-northeast of the Shas prospect (Figure 2-14-1). Three areas of favourable geology were identified: the south side of Jock Creek; a quartz-chalcedonic breccia zone; and the White Creek area.

On the south side of Jock Creek an EMR-16 resistivity survey identified four anomalies, over a strike length of 825 metres, which are open to the north and south (Plate 2-14-5). Several zones of quartz-barite breccia epithermal veining in Toodoggone volcanic tuffs and hypabyssal syenite have been found in this area. Disseminated pyrite with minor galena, sphalerite and chalcopyrite occur in the veins. A mineralized quartz-chalcedonic breccia zone, located at a higher elevation to the south, has been traced by an EMR-16 resistivity survey for 700 metres. Hand trenching has exposed an area with encouraging gold and silver values. In the White Creek area, 2.5 kilometres to the southeast, there are two parallel quartz-chalcedonic breccia zones at timberline with silver and gold values. Mechanical trenching and drilling will be required to assess the potential of these showings.

GOLDEN NEIGHBOUR (SAUNDERS, MI 94E-037) — LACANA MINING CORP.

In 1986 Lacana Mining Corp. completed five diamond-drill holes totalling 610 metres to test a quartz zone on their Golden Neighbour property 7 kilometres northeast of the Baker mine. The holes were drilled from three setups and tested 150 metres of strike length within a 1200-metre-long soil anomaly with gold values up to 1800 ppb (Figure 2-14-3). Intersections of the quartz zone averaged 10 to 12 metres in length and contained minor pyrite and chalcopyrite as disseminations and "patches"; a pinkish alteration halo is present in the wallrock. Minor amethyst occurs locally in the host rock, a green feldspar andesite porphyry. Geochemically anomalous values range up to 1000 ppb gold, but no high-grade mineralization was intersected.

METSANTAN (MI 94E-064) — LACANA MINING CORP.

During 1986 Lacana Mining Corp. completed five diamond-drill holes totalling approximately 610 metres on the Patti zone located on the northwest flank of Metsantan Mountain, immediately south of the Energex Al claim boundary (Figure 2-14-2). The holes intersected intensely silicified and pyritized andesitic rocks. The Patti zone, exposed over an area 230 metres by 400 metres, appears typical of several structurally related high silica-clay + barite + native gold alteration zones occurring north of Metsantan Mountain.

GOLDEN STRANGER (MI 94E-076) — WESTERN HORIZONS RESOURCE LTD.

Western Horizons Resources Ltd. carried out hand trenching, geological mapping and sampling over a quartz-amethyst epithermal breccia system in Toodoggone andesitic rocks (Plate 2-14-6). The zone has been traced for a strike length of over 600 metres. The breccia zone is commonly 2.5 to 4 metres wide. Sulphides identified to date are pyrite, galena, sphalerite and chalcopyrite. An aplite dyke follows the north-trending structure but is rarely mineralized. Grab samples have been collected for assay.

SHAS (MI 94E-50) — INTERNATIONAL SHASTA RESOURCES LTD.

No work was carried out in 1986 on the Shas property because of a legal dispute over tenure. During the summer the court case involving International Shasta Resources Ltd., Newmont Exploration of Canada Ltd. and Arctic Red Resources Ltd. ruled in favour of International Shasta Resources (*see* Table 2-14-1 for results from previous years).

ACKNOWLEDGMENTS

The writers gratefully acknowledge the hospitality and information provided by company personnel from Canasil Resources Inc., Cyprus Metals Canada Ltd., Energex Minerals Ltd., Lacana Mining Corp., Manson Creek Resources Ltd., Multinational Resources Inc. and Western Horizons Resources Ltd.

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Regional Mapping

QUESNEL GOLD BELT — ALKALIC VOLCANIC TERRANE BETWEEN HORSEFLY AND QUESNEL LAKES*
(93A/6)

By Andrejs Panteleyev

INTRODUCTION

A four-year geological mapping program, the Quesnel Project, funded by the Canada/British Columbia Mineral Development Agreement (MDA) was initiated in 1986. It is primarily intended to study the geological setting and economic potential for gold and copper-gold deposits in the central volcanic-intrusive axis of the Quesnel belt, previously known as the Quesnel trough (Figure 3-1-1).

This report outlines results of the first summer's fieldwork during which 180 square kilometres were mapped at scale 1:15 840 (1 inch to ¼ mile) between the western end of Horsefly and Quesnel Lakes (Figure 3-1-2). An attendant study, conducted as part of the Quesnel Project by Mary Anne Bloodgood, is an investigation of the basal black phyllite units that underlie the volcanic rocks and flank them to the east and southeast; see the accompanying report by M.A. Bloodgood, this volume.

The project area is within the south-central portion of the Quesnel terrane, an allochthonous belt of predominantly Upper Triassic-Lower Jurassic basic to intermediate volcanic rocks that lies along the eastern margin of the Intermontane Belt. Quesnel terrane can be followed as a disrupted but nearly continuous narrow belt, from the southern to northern provincial boundaries. The belt includes rocks of the Quesnel River, Nicola, Takla, Stuhini and Rossland Groups (Tipper *et al.*, 1971). Quesnel terrane in the project area is a fault-bounded region that is flanked to the east by Precambrian to Paleozoic rocks of the Barkerville and Slide Mountain terranes (Struik, 1986) and to the west by Paleozoic rocks of the Cache Creek terrane.

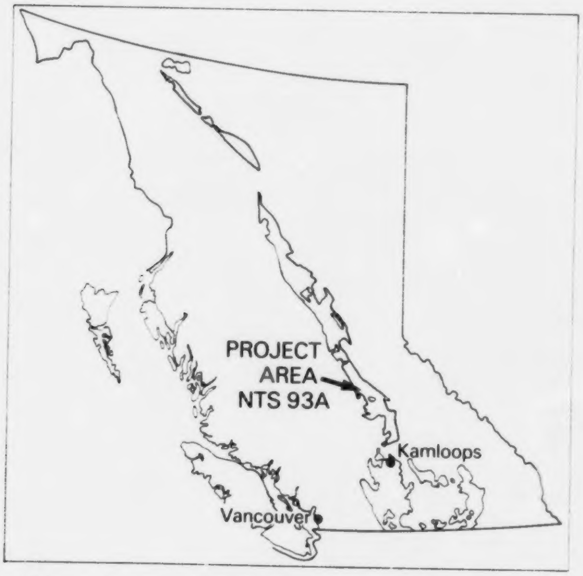

Figure 3-1-1. Location of the project area in Quesnel terrane (shaded area).

PREVIOUS WORK

Triassic volcanic rocks were first recognized to the south near Kamloops by G.M. Dawson and in the Quesnel River region by Amos Bowman in 1887. The broad extent of Triassic rocks was discovered in the 1940s and 1950s and in the 1960s they were interpreted to be part of a volcanic arc that is continuous throughout the Cordillera. Comprehensive regional studies in the Quesnel River area were made by the Geological Survey of Canada in the late 1950s and 1960s and are summarized by Campbell, 1978 (Geological Survey of Canada, Open File Map 574). The first synopsis of mineral potential in the region was by Campbell and Tipper (1970).

The alkaline nature of the volcanic rocks and related plutons became evident during the 1970s largely from work by Fox (1975) and Ministry work near Princeton by Preto (1979). Detailed stratigraphic and petrologic studies were by Lefebure (1976), Morton (1976) and Bailey (1978). Alkalic pluton-related mineralization was discussed by Barr *et al.* (1976) and Hodgson *et al.* (1976).

Placer gold in the Quesnel River drainage system has been historically important. Bedrock exploration in Quesnel River area was active during the late 1960s and throughout the 1970s, first for copper and copper-gold porphyry deposits and more recently for gold deposits (Saleken and Simpson, 1984). Exploration activity peaked in the early 1980s after release of the 1980 Regional Geochemical Survey (RGS) and recognition of the significance of the Quesnel River (QR) deposit. There Dome Exploration (Canada) Ltd. has discovered about one million tonnes of near-surface mineralization in altered basalts, containing some 8 tonnes of gold reserves (Fox, Cameron and Hoffman, in press).

STRATIGRAPHY

The scarcity of outcrops, abundant block faulting and similar appearance of map units within the basaltic sequence make correlation of many map units difficult. However some coarse-grained plagioclase pyroxene basalt and analcite-bearing rocks provide distinctive, readily identifiable map units.

The stratigraphic sequence consists predominantly of subaqueous pyroxene-phyric basalt flows, flow breccia, debris flow or lahar deposits and locally developed volcaniclastic and epiclastic rocks. These rocks overlie a basal sequence of basaltic-source volcanic sandstone and are in fault contact with younger feldspathic polylithic volcaniclastic rocks. The basaltic rocks are calc-alkalic to alkalic (shoshonitic) in composition and have associated cogenetic stocks of diorite to monzonite composition (Table 3-1-2). Most of the rocks lack modal quartz and many have nepheline and/or olivine in the normative mineralogy. They all contain abundant modal pyroxene. Some distinctive rocks also contain coarse-grained plagioclase laths up to 1.5 centimetres in length; others contain olivine or analcite.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

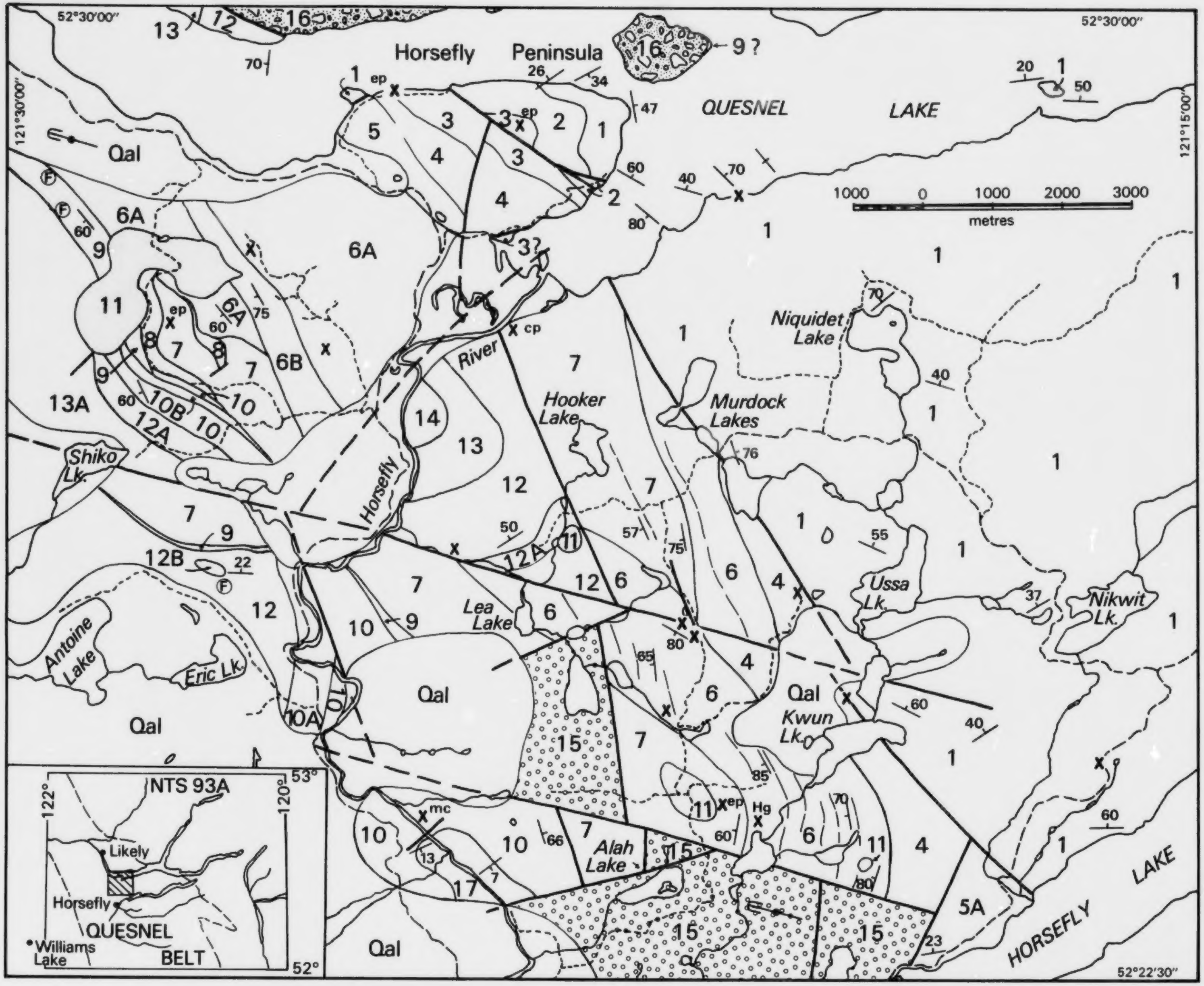
52°30'00"
52°30'00"
121°30'00"
121°15'00"
52°22'30"
Horsefly Peninsula
QUESNEL LAKE
HORSEFLY LAKE
Horsefly River
Niquidet Lake
Murdock Lakes
Hooker Lake
Lea Lake
Ussa Lk.
Nikwit Lk.
Kwun Lk.
Alah Lake
Shiko Lk.
Antoine Lake
Eric Lk.
Qal
9 ?
1000 0 1000 2000 3000
metres
NTS 93A
53°
52°
122°
120°
Likely
Horsefly
Williams Lake
QUESNEL BELT

Figure 3-1-2. Geology of the central Quesnel terrane between Horsefly and Quesnel Lakes.

LEGEND

QUATERNARY

PLEISTOCENE AND RECENT

Qal	*Glacial and fluvial deposits; alluvium*

TERTIARY

EOCENE OR (?) YOUNGER

17	*Pale grey to yellow grey sandstone, siltstone*

JURASSIC

LOWER AND (?) MIDDLE JURASSIC

16	*Conglomerate with orange weathering carbonate matrix; polymictic with predominantly metasedimentary and rare granitic clasts*

LOWER JURASSIC

15	*Volcaniclastic rocks; pale to dark brown, grey and lavender polylithologic conglomerate and breccia containing 'felsic' feldspathic clasts*
14	*Dark grey to green grey polymictic volcanic breccia*
13	*Dark green to grey alkali olivine basalt;* *13A — pyroxene basalt breccia*
12	*Dark grey to black analcite — pyroxene basalt;* *12A — analcite crystal-lithic ash and lapilli tuff;* *12B — brownish black sandstone and siltstone*
11	*Diorite, monzonite and related dykes*

SYMBOLS

Trends of well bedded volcaniclastic units within major map units ....

Main roads ....

Logging and secondary roads ....

Quartz-carbonate alteration with pyrite and/or marcasite — Mc, cinnabar — Hg x

Propylitic alteration with pyrite, epidote, calcite, chlorite, actinolite and minor garnet and chalcopyrite — cp .... xep

TRIASSIC AND JURASSIC

UPPER TRIASSIC AND (?) YOUNGER

10	*Green black to dark grey brown pyroxene basalt;* *10A — fine-grained basalt; 10B — maroon pyroxene basalt breccia with mudstone matrix*
9	*Dark brown sandstone, siltstone; limestone dominant locally*
8	*Pale grey to pink breccia, intrusive in part.* *Monzonitic breccia with volcanic clasts; flow layered lithic tuff and breccia*
7	*Grey to greyish green plagioclase-pyroxene phyric basalt; mainly autobrecciated flows. Extensively epidotized with pyrite near diorite intrusions*
6	*Dark olive grey, grey to black pyroxene basalt and intercalated volcaniclastic rocks;* *6A — includes fine-grained basalt flows or dykes, tuff and volcaniclastic sandstone, greywacke or pyroxene crystal tuff* *6B — polymictic debris flows or lahar*
5	*Brownish black to olive black, dusky red to reddish brown weathering alkali olivine basalt; breccia, pillow breccia and locally hyaloclastite*
4	*Green grey to black pyroxene basalt flow breccia; includes some pyroclastic breccia and slide debris. Top of unit locally contains dykes of map unit 5 olivine basalt. Basal part contains medium-grained plagioclase phenocrysts*
3	*Grey to grey green, rusty weathering pyroxene hornebende basalt or andesitic basalt. Breccia in part, extensively pyritic*
2	*Dark green to black pyroxene basalt*
1	*Dark greenish grey to olive grey greywacke, siltstone; locally chert and argillite with thin limestone lenses. Some beds contain abundant olivine and pyroxene grains*

Morton (1976) studied a large area that includes the area described in this report. He subdivided the rocks into 29 map units and identified three main cycles of magmatic activity. Morton's study provides much petrologic description and chemical analyses but none of his stratigraphy is retained in this study. Bailey (1976 and 1978) completed a similar study to the northwest of Morton and this project; Bailey's stratigraphy is compatible with this study. His two older map units and their subdivisions are equivalent to the map units shown on Figure 3-1-2. Bailey's Unit 1 is equivalent to this study's Unit 1; his Unit 2, with its seven subunits, corresponds to this study's Units 2 through 14.

The following map units representing an approximately 5-kilometre-thick sequence are shown on Figure 3-1-2:

UNIT 1: Volcanic-source sandstone and siltstone, minor chert and limestone lenses. A thinly bedded sequence containing turbidite members and beds with abundant olivine and pyroxene grains and limestone clasts.

UNIT 2: Dark green pyroxene basalt flows and flow breccia. Generally chloritized, with abundant calcite veinlets.

UNIT 3: Pale grey-green, pyritic, pyroxene hornblende basalt or basaltic andesite. Breccia in part. Pyritic rocks contain epidote and are rusty weathering.

UNIT 4: Alkalic pyroxene basalt. Coarse pyroxene-phyric flows, mainly autobrecciated flows; some pyroclastic breccia. Includes flow units containing fine to medium-grained plagioclase laths.

UNIT 5: Alkali-olivine basalt and pyroxene basalt autobrecciated flows and pillow breccia. Limestone is common in small lenses or as breccia matrix or clasts. 5A — Breccia debris flows or lahar.

UNIT 6: Pyroxene-phyric basalt. Pyroclastic and volcaniclastic breccias with variably oxidized green to purple and reddish coloured clasts in a mixed sequence of coarse breccia and tuffs. Many clasts are amygdaloidal or vesicular. Unit contains pyroxene-rich greywacke or crystal tuff, debris flows or lahar. Includes: 6A — massive flows of fine-grained basalt; 6B — polymictic lahar with predominantly Unit 6 debris but also diabase and feldspar-bearing clasts of volcanic or dyke rocks, and 6C — thinly bedded greywacke, pyroxene crystal lithic ash to lapilli tuff or epiclastic beds.

UNIT 7: Plagioclase pyroxene-phyric basalt flows and distinctive coarse fragmental monomictic autobrecciated units. Contains limestone blocks and breccia matrix in coarse slump debris at top of unit. Generally contains some epidote; strongly epidotized with abundant pyrite and rare garnet near intrusive rocks.

UNIT 8: Pink-weathering monzonite-latite breccia. Intrusive breccia adjoining the Shiko stock but part of the layered volcanic sequence further away. Milled polylithologic volcanic clasts in a dioritic matrix. Epidotized and weakly pyritic.

UNIT 9: Sandstone, siltstone; minor chert, locally predominantly limestone. Contains some Sinemurian faunal debris.

UNIT 10: Pyroxene basalt, mainly medium-grained pyroxene-phyric basalt flow breccia. Possibly locally analcite-bearing. Unit 10A — fine-grained to aphanitic basalt with sparse pyroxene phenocrysts; 10B — maroon basalt breccia with red mud matrix and lenses.

UNIT 11: Diorite and monzonite intrusions — small stocks, medium-grained equigranular to porphyritic, containing hornblende and biotite. Includes a related suite of dykes — differentiated from alkalic gabbro to hornblende syenite and felsic potassium-feldspar porphyries.

UNIT 12: Analcite-bearing pyroxene basalt flows and flow breccia. Includes 12A — analcite crystal-lithic ash tuff and interbedded thin flows; 12B — sandstone and siltstone, locally with faunal debris.

UNIT 13: Alkalic-olivine pyroxene basalt breccia. Includes 13A — pyroxene breccia; some lapilli tuff and rare amygdaloidal pillow basalt and pillow breccia.

UNIT 14: Breccia — dark grey to green polymictic breccia containing mainly pyroxene basalt clasts but also hornblende and plagioclase-bearing basaltic andesite debris.

UNIT 15: Polylithologic conglomerate and breccia; some feldspathic "felsic breccia"; locally arkosic sandstone. Very mixed clast lithologies, primarily feldspathic volcanic debris but includes clasts of intrusive rocks.

UNIT 16: Conglomerate and sandstone. Calcareous matrix, commonly orange-weathering with polymictic clasts derived from metamorphic and granitic terranes.

UNIT 17: Lacustrine siltstone. Laminated pale grey beds with abundant floral debris and rare fish imprints. Unconformably overlies volcanic rocks along a highly oxidized and weathered rock-paleosol surface.

AGES OF MAP UNITS

The main basaltic volcanic sequence (Units 2 to 7) and the basal basalt-derived sedimentary unit (Unit 1) are shown by Campbell (1978), to be Norian and possibly younger; the analcite-bearing rocks and maroon basaltic breccia and related sediments of Units 9, 10 and 12 are Norian to Sinemurian. Bailey (1978), on the basis of some additional faunal data, considers the basal sedimentary unit to be Carnian, the main volcanic sequence Norian, and the overlying polylithologic felsic volcaniclastic units earliest Jurassic.

The younger conglomerates (Unit 16) are identical to rocks 20 kilometres to the northwest along the Quesnel River between Likely and Quesnel Forks. Both Campbell and Bailey regard these as Pleinsbachian to Bajocian (Lower to Middle Jurassic).

Three fossil localities sampled during this mapping rendered indeterminable fragments of bivalves, gastropods, corals and sparse ammonites. The sites were extensively sampled in 1986 by H. Tipper (personal communication) and produced abundant Sinemurian fauna.

Results of radiometric dating of four diorite to monzonite stocks are shown on Table 3-1-1. The stocks sampled are the Bullion stock at the site of the Bullion placer mine near Likely, the Shiko Lake stock, and the Quesnel River (QR) stock 8 kilometres downstream from Quesnel Forks. The potassium-argon dates are similar to the previously reported ages from the Shiko Lake stock — 190 million years (Schink, 1974) and the Lemon Lake stock — 192 million years (Pilcher and McDougall, 1976).

PETROCHEMISTRY

Fifteen samples were analysed for major oxide and rare earth elements (REE) (Tables 3-1-2 and 3-1-3; Figures 3-1-3 and 3-1-4). These are additional to the nearly 100 analyses reported by Morton (1976) and Bailey (1978). The new data reaffirm that the volcanic suite is a calc-alkaline to alkaline assemblage of alkaline olivine basalt and alkaline basalt that has undergone little fractional crystallization. The sequence in the map area, with the exception of Unit 15, does not contain the trachyandesite and trachyte felsic breccia sequence described by Bailey. The rocks are typical of other deep water calc-alkaline to alkaline (shoshonitic) island arc rocks with low TiO_2 and moderately elevated light REE values (Spence, 1985).

TABLE 3-1-1.
POTASSIUM-ARGON ANALYTICAL DATA, QUESNEL RIVER ALKALIC STOCKS

Sample Number	Location (UTM)	Lithology	Material Analysed	%K	Ar^{40*} 10^{-10} (moles/gm)	$\frac{Ar^{40*}}{Total\ Ar^{40}}$	Apparent Age (Ma)
(1) 85AP-8/9-71	591900E, 5831900N	Bullion pit stock, diorite	Biotite	5.40	19.037	87.7	193 ± 7
(2) 85AP-7/2-63	603750E, 5812800N	Shiko stock, hornblende porphyry dyke	Hornblende	0.828	2.967	91.8	196 ± 7
(3) 85AP-8/1-64	603550E, 581300N	Shiko stock, monzonite core zone	Biotite	4.67	16.408	86.7	192 ± 10
(4) 85AP-21/2-120	581450E, 5835300N	QR stock, diorite	Biotite (chloritized)	3.95	14.565	95.2	201 ± 7

* Radiogenic Ar.

Constants: $\lambda^{40}K\varepsilon = 0.581 \times 10^{-10} yr^{-1}$; $\lambda^{40}K\beta = 4.96 \times 10^{-10} yr^{-1}$; $^{40}K/K = 1.167 \times 10^{-4}$.
%K determined by the Analytical Laboratory, British Columbia Ministry of Energy, Mines and Petroleum Resources, Victoria.
Ar determination and age calculation by J.E. Harakal, The University of British Columbia.

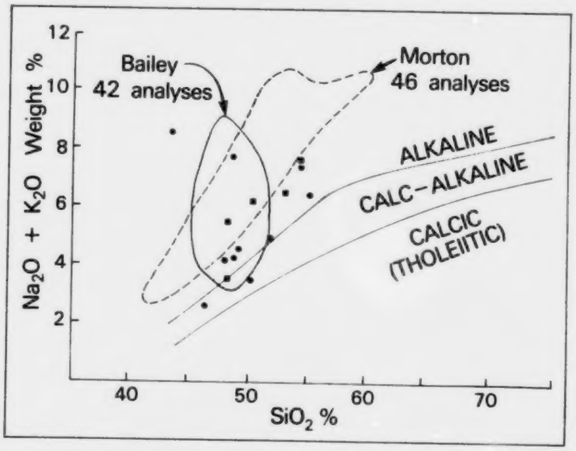

Figure 3-1-3. Alkali-silica diagram. New analyses: volcanic rocks, circles; intrusive rocks, squares. Fields of analysed samples from Morton (1976) and Bailey (1978). Field boundaries modified from Kuno by Spence (1985).

The breccia (Unit 8) associated with the Shiko Lake stock is intermediate in character (analyses 31600 and 31603) and similar in composition to the diorite and monzonite stocks analysed (samples 31601, 31602, 31605, 31606, 31610 and 31612).

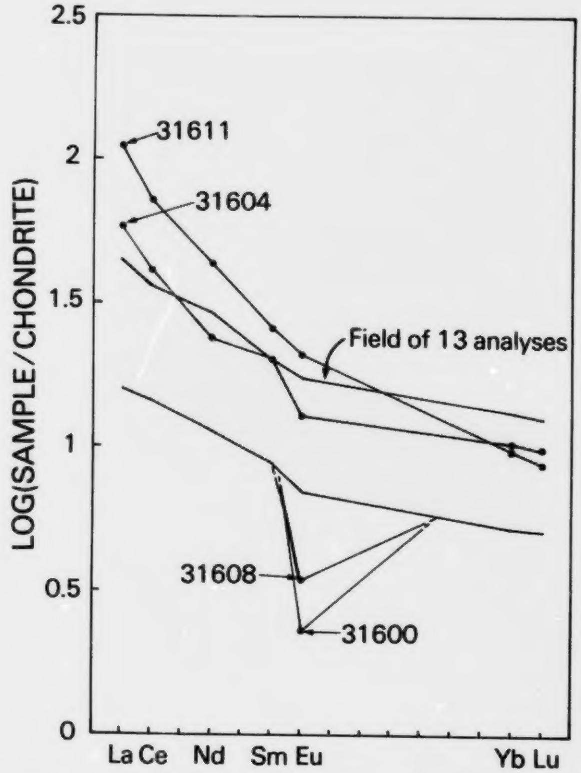

Figure 3-1-4. Chondrite normalized rare earth element (REE) plot for 15 samples (31597 to 31612).

STRUCTURE

The region is extensively block faulted with generally steeply dipping, southwesterly to west-facing panels of poorly bedded volcanic rocks. The basal sedimentary unit is complexly folded but there is little development of any penetrative foliation. Between Horsely and Quesnel Lakes the basal unit is in fault contact with the overlying volcanic rocks; on Horsefly Peninsula it is conformably overlain by pyroxene-phyric basalt flows.

In the south and southwestern part of the map area (Figure 3-1-2) between Horsefly Lake and Horsefly River, there appears to be a series of small grabens containing felsic-clast conglomerates. These might be part of a series of larger, northwesterly trending grabens along the medial axis of the volcanic arc. A similar structure is shown to the northwest by Bailey (1978).

An invaluable aid to locating faults, tracing map units across faults and providing correlation between fault blocks, is provided by regional aeromatic maps (Aeromagnetic Series Map 5239G, 1:63 360). The magnetic highs (Figure 3-1-5) outline alkalic intrusive centres and analcite-bearing volcanic units (total field strength 4000 to 5000 gammas). Magnetic troughs correspond to the coarse

TABLE 3-1-2. CHEMICAL ANALYSIS AND CIPW NORMS FOR INTRUSIVE AND VOLCANIC ROCKS

OXIDES AS DETERMINED

Sample	31597	31598*	31599	31600	31601	31602	31603	31604	31605	31606	31607	31608	31609	31610	31611	31612
SiO_2	49.19	43.82	48.13	55.18	42.20	54.34	54.40	48.07	50.35	48.20	46.80	50.32	49.28	53.55	48.51	52.36
TiO_2	0.57	0.65	0.61	0.64	1.04	0.55	0.55	0.76	0.68	0.99	0.55	0.51	0.97	0.77	0.69	0.63
Al_2O_3	11.15	15.39	9.94	17.31	14.98	18.07	16.75	16.23	15.61	17.80	9.23	10.64	11.41	17.93	16.63	17.34
Fe_2O_3	6.12	6.34	6.35	5.23	2.72	4.43	3.70	5.55	6.14	6.20	5.22	4.11	2.74	4.39	4.22	4.75
FeO	4.51	1.91	5.37	4.22	8.33	3.57	3.43	4.14	5.28	4.64	5.43	5.86	6.08	4.41	4.91	3.44
MnO	0.16	0.19	0.20	0.24	0.22	0.15	0.14	0.19	0.21	0.11	0.18	0.19	0.15	0.19	1.21	0.16
MgO	9.21	2.78	10.63	4.05	6.16	3.33	4.42	5.56	4.95	4.13	10.96	12.54	7.59	3.01	4.07	3.28
CaO	12.96	11.06	13.33	5.21	9.25	6.76	5.88	11.18	9.31	9.65	15.18	9.51	13.13	7.41	6.80	6.62
Na_2O	3.51	4.45	1.56	5.11	2.97	4.00	3.13	2.91	2.48	3.02	1.57	11.50	4.29	3.71	4.68	3.79
K_2O	0.65	4.06	2.18	1.30	1.82	3.56	4.38	1.13	3.65	2.50	0.93	1.88	0.04	2.55	2.96	3.74
P_2O_5	0.45	0.50	0.32	0.33	0.33	0.48	0.26	0.62	0.48	0.39	0.29	0.24	0.22	0.42	0.54	0.48
CO_2	0.70	5.50	0.11	0.10	0.10	0.10	1.11	0.10	0.34	0.34	0.38	0.20	3.27	0.10	0.73	0.11
H_2O-	0.31	0.38	0.44	0.37	0.13	0.13	0.31	0.16	0.05	0.11	0.29	0.43	0.12	0.20	1.25	0.16
H_2O+	1.34	3.47	1.48	2.00	0.64	0.86	0.78	2.40	0.08	2.00	1.75	2.28	1.60	1.11	3.45	0.82
Total	100.83	100.50	100.65	101.23	100.89	100.33	99.24	99.00	99.61	100.08	98.76	100.11	100.89	99.80	98.65	97.68

OXIDES RECALCULATED VOLATILE FREE

Sample	31597	31598*	31599	31600	31601	31602	31603	31604	31605	31606	31607	31608	31609	31610	31611	31612
SiO_2	49.95	48.08	48.80	55.84	52.19	54.76	56.06	49.90	50.79	49.37	48.58	51.72	51.39	54.45	51.49	54.21
TiO_2	0.58	0.71	0.62	0.65	1.04	0.55	0.57	0.79	0.69	1.01	0.57	0.52	1.01	0.78	0.73	0.65
Al_2O_3	11.32	16.89	10.08	17.52	14.98	18.21	17.26	16.85	15.75	18.23	9.58	10.94	11.90	18.23	17.65	17.95
Fe_2O_3	6.21	6.96	6.44	5.29	2.72	4.46	3.81	5.76	6.19	6.35	5.42	4.22	2.86	4.46	4.48	4.92
FeO	4.58	2.10	5.45	4.27	8.33	3.60	3.53	4.30	5.33	4.75	5.64	6.02	6.34	4.48	5.21	3.56
MnO	0.16	0.20	0.20	0.24	0.22	0.15	0.14	0.20	0.21	0.11	0.19	0.20	0.16	0.19	0.22	0.17
MgO	9.35	3.05	10.78	4.10	6.16	3.36	4.55	5.77	4.99	4.23	11.38	12.89	7.91	3.06	4.32	3.40
CaO	13.16	12.13	13.52	4.27	9.25	6.81	6.06	11.60	9.39	9.88	15.76	9.77	13.69	7.54	7.22	6.85
Na_2O	3.56	4.88	1.58	5.17	2.97	4.03	3.23	3.02	2.50	3.09	1.63	1.54	4.47	3.77	4.97	3.92
K_2O	0.66	4.45	2.21	1.32	1.82	3.59	4.51	1.17	3.68	2.56	0.97	1.93	0.04	2.59	3.14	3.87
P_2O_5	0.46	0.55	0.32	0.33	0.33	0.48	0.27	0.64	0.48	0.40	0.30	0.25	0.23	0.43	0.57	0.50
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

CIPW NORM VOLATILE FREE

Sample	31597	31598*	31599	31600	31601	31602	31603	31604	31605	31606	31607	31608	31609	31610	31611	31612
Q	0.00	0.00	0.00	3.70	0.00	0.42	1.77	0.48	0.00	0.00	0.00	0.00	0.00	3.50	0.00	0.00
Or	3.89	26.25	13.06	7.77	10.75	21.20	26.67	6.93	21.76	15.13	5.70	11.42	0.25	15.32	18.56	22.88
Ab	24.86	9.20	12.68	43.74	25.12	34.09	27.28	25.55	21.16	25.94	12.34	13.04	26.27	31.91	29.03	33.19
An	12.96	10.98	13.88	20.72	22.18	21.01	19.30	29.96	20.87	28.31	15.98	17.22	12.27	25.17	16.60	19.95
Lc	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ne	2.86	20.70	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.78	0.00	6.27	0.00	7.03	0.00
Di	38.85	9.37	40.34	2.60	17.76	7.68	7.17	19.29	18.05	14.36	47.72	23.57	43.59	7.62	12.50	8.57
Hy	0.00	0.00	0.00	11.82	15.51	6.98	10.61	7.47	4.39	0.00	0.00	24.87	0.00	7.55	0.00	5.43
Ol	5.42	6.30	8.42	0.00	2.11	0.00	0.00	0.00	2.40	4.10	7.85	2.21	4.78	0.00	7.08	0.48
Wo	0.00	9.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	Q.00	0.00	0.00
Mt	9.01	3.37	9.33	7.67	3.94	6.47	5.53	8.35	8.98	9.21	7.86	6.12	4.14	6.47	6.49	7.13
Il	1.10	0.99	1.17	1.23	1.97	1.05	1.08	1.50	1.30	1.93	1.08	1.00	1.92	1.49	1.39	1.24
Hm	0.00	2.59	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ap	1.07	1.00	0.76	0.78	0.77	1.13	0.62	1.50	1.13	0.93	0.70	0.57	0.53	1.00	1.34	1.16
AN =	34.27	53.00	52.25	32.14	46.89	38.13	41.43	53.13	49.66	52.19	56.43	56.91	31.85	44.10	36.38	37.54

Analyses by X-ray fluorescence, Analytical Laboratory, British Columbia Ministry of Energy, Mines and Petroleum Resources.
*31598 — Calcite-bearing analcite crystal tuff with unusual CIPW norm; 31612 is duplicate of 31602.

TABLE 3-1-3. TRACE AND RARE EARTH ELEMENT ANALYSES

(in ppm)

Sample Number	La	Ce	Nd	Sm	Eu	Yb	Lu	Se	Br	Sb	As	Ba	Rb	Sr	Y	Nb	Sv	Cs	Th	U	Hf	Ta	Cr	Co
31597	10.0	21	9	2.4	0.7	1.5	0.20	<5	<1.1	1.0	11	200	<30	620	12	4	54.0	<1.4	1.0	1.1	<1	<1	620	62
31598	15.0	30	11	3.2	1.1	2.1	0.36	<5	<0.9	0.4	26	1000	50	770	20	4	18.0	2.9	2.1	1.7	1	<1	30	26
31599	7.0	14	8	2.2	0.6	1.5	0.22	<5	<1.0	0.2	4	900	40	410	12	4	64.3	1.9	0.9	0.5	<1	<1	600	65
31600	8.0	19	9	2.7	<0.2	2.4	0.31	<5	1.0	0.7	6	700	40	480	22	4	29.2	<0.5	1.1	1.1	<1	<1	30	21
31601	11.0	26	11	3.9	1.5	3.3	0.49	<5	2.4	2.4	4	1100	50	390	26	6	41.3	2.3	1.4	1.2	2	<1	170	49
31602	14.0	27	15	3.1	0.7	2.1	0.32	<5	1.5	0.7	2	1500	90	770	18	4	21.5	1.4	3.0	1.7	2	<1	10	38
31603	15.0	35	13	3.7	1.1	2.5	0.39	<5	1.2	1.0	14	1500	100	510	24	4	26.2	<0.5	2.3	1.1	2	<1	220	19
31604	22.0	40	17	4.6	1.1	2.6	0.38	<5	<1.0	3.5	16	800	40	760	20	6	33.8	10.0	2.6	4.7	2	<1	470	28
31605	13.0	28	11	3.4	0.9	1.9	0.23	<5	1.2	0.2	2	1200	100	780	16	4	38.3	<1.3	1.2	0.9	<1	<1	40	52
31606	12.0	23	13	3.5	0.9	2.0	0.34	<5	<0.9	0.3	7	1000	80	600	22	4	30.4	<1.2	1.2	1.0	1	<1	10	36
31607	9.0	15	11	2.6	0.9	1.3	0.22	<5	<1.2	<0.2	<2	800	<20	470	10	4	91.4	2.8	1.2	<0.5	<1	<1	310	56
31608	7.0	17	9	2.0	0.3	1.9	0.24	<5	<0.9	3.3	7	500	50	330	14	4	40.3	2.9	1.1	0.8	1	<1	1000	57
31609	6.0	19	9	3.1	0.7	2.3	0.33	31	<1.1	1.9	9	<100	<30	300	18	4	45.9	<1.4	0.3	<0.5	2	<1	1100	64
31610	17.0	30	21	4.1	1.4	2.5	0.38	<5	<1.0	0.4	<2	1500	80	560	24	6	23.9	3.0	3.6	2.2	2	1	10	35
31611	42.0	70	31	5.9	1.8	2.4	0.34	<5	<1.2	0.5	7	1100	110	630	24	10	30.8	2.0	8.3	3.2	2	<1	40	29
31612	14.0	28	13	3.1	1.0	2.2	0.30	<5	<0.9	0.4	2	1500	90	770	20	6	21.9	1.8	2.3	1.1	2	<1	10	42

SAMPLE DESCRIPTIONS TO ACCOMPANY TABLES 3-1-2 and 3-1-3

Number	Sample	Map Unit	Location	Description
(1) 31597	85AP-1/1-35A	13A	Shiko Lake	Clast from coarse breccia; clast-supported angular blocks, mainly coarse-grained pyroxene-phyric basalt
(2) 31598	85AP-3/5-41	12A	Shiko Lake	Analcite crystal ash lithic tuff
(3) 31599	85AP-5/8-56A	11	Shiko stock	Mafic coarse-grained biotite syenite, lamprophyre
(4) 31600	85AP-5/9-57	8	Shiko Lake	Intermediate breccia, in part intrusive
(5) 31601	85AP-7/2-63	11	Shiko stock	Hornblende porphyry-syenite dyke
(6) 31602	85AP-8/1-64	11	Shiko stock	Medium-grained pink monzonite, core zone of Shiko stock
(7) 31603	85AP-8/6-67	8	Shiko Lake	Intermediate breccia, extrusive equivalent to sample 85AP-5/9-57
(8) 31604	85AP-8/6-68	7	Shiko Lake	Clast from coarse monomictic autobreccia of coarse-grained plagioclase pyroxene porphyritic basalt
(9) 31605	85AP-8/7-69	11	Shiko stock	Medium-grained grey diorite, main phase Shiko stock
(10) 31606	85AP-8/9-71	11	Bullion stock (Likely)	Medium-grained grey diorite, main phase Bullion stock
(11) 31607	85P-9/1-72	5	Horsefly River road near Mitchell Bay	Olivine pyroxene basalt, brecciated, locally with limestone matrix, in part hyaloclastite
(12) 31608	85AP-12/4-84	7	Shiko Lake	Pyroxene-phyric basalt, monomictic breccia underlying map Units 7 and 8
(13) 31609	85AP-20/2-115	2	Horsefly Peninsula	Pyroxene basalt breccia clast
(14) 31610	85AP-21/2-120	11	QR stock	Medium-grained diorite, main phase
(15) 31611	85AP-22/3-123	3	Horsefly Peninsula	Basaltic andesite breccia, clast of main lithologic type from polylithic breccia
(16) 31612	85AP-8/1-64	11	Shiko stock	Duplicate analyses of 31602

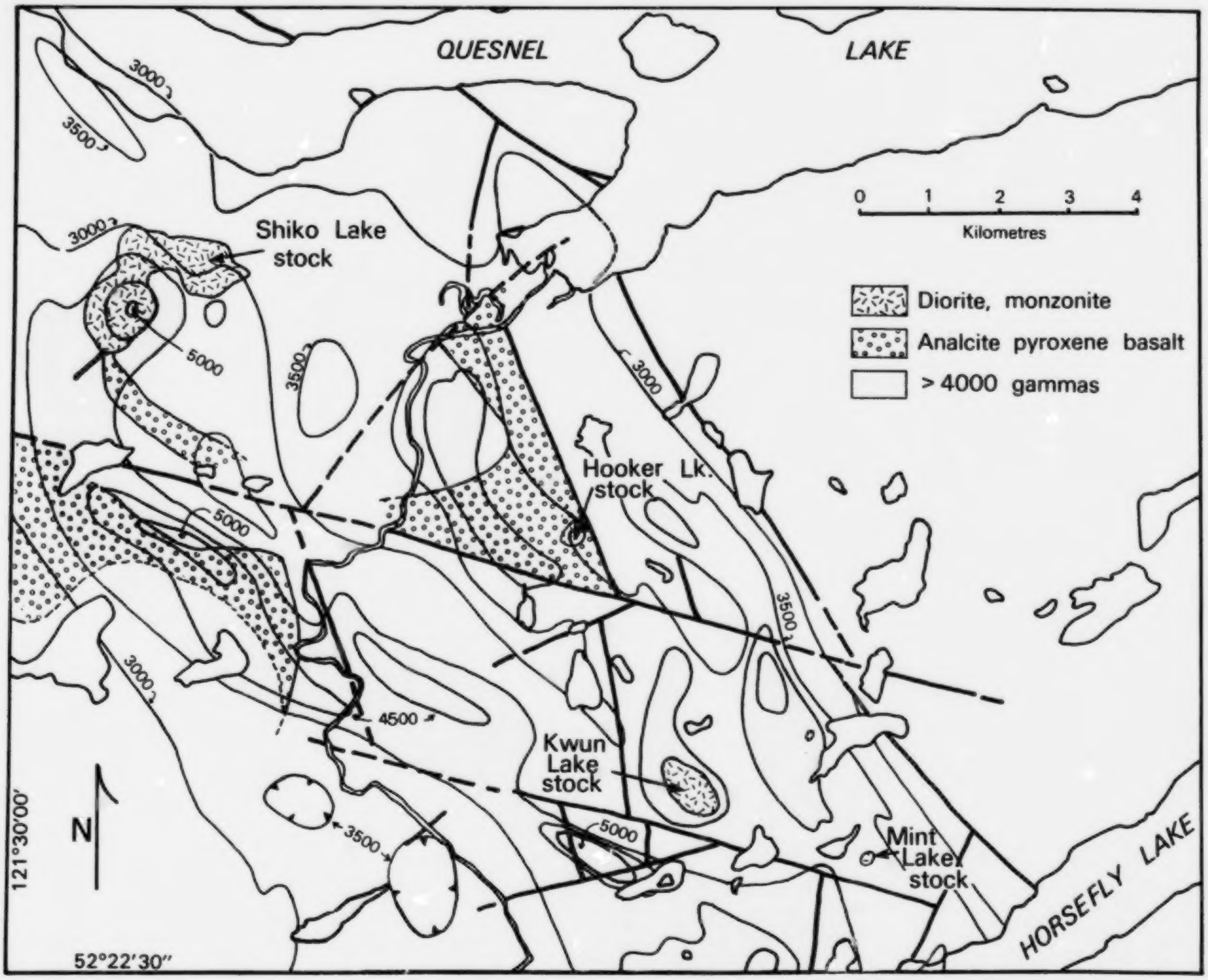

Figure 3-1-5. Total field strength aeromagnetic patterns outlined by high magnetic susceptibility diorite/monzonite stocks, analcite pyroxene basalts, and low susceptibility sedimentary rocks.

plagioclase pyroxene-phyric flows and flow breccias of Unit 7. The low magnetic susceptibility (2500 to 3000 gammas) of the basal sedimentary unit allows clear definition of its contact with overlying volcanic rocks.

ALTERATION AND MINERALIZATION

The alkalic intrusive stocks, particularly stocks near Shiko and Kwun Lakes, have been explored for porphyry copper and skarn mineralization but without notable success. The volcanic rocks surrounding these and the other small stocks or intrusive-extrusive breccia zones are extensively epidotized, chloritized and pyritic. Zeolites are widespread. These zones are being re-evaluated for their gold potential and comparisons drawn with the propylite-related QR deposit (Fox *et el.*, in press).

During this mapping project a number of orange-weathering carbonate and quartz-carbonate hydrothermal alteration zones were noted; some contain pyrite and/or marcasite. The alteration is related to small fault or fracture zones in basalts. One, on the Beekeeper property southwest of Kwun Lake, contains visible cinnabar. This zone appears to be associated with a number of small hornblende porphyry or hornblende syenite dykes.

The overall association of broad pervasive propylite alteration with intrusive rocks, iron and mercury sulphide-bearing quartz-carbonate alteration with fractured basaltic rocks, and widespread zeolite, imply large low temperature hydrothermal fluid systems. These indications are compatible with low temperature gold deposits or peripheral zones of mesothermal gold deposits and therefore provide some encouragement for further exploration.

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GEOLOGY OF THE TRIASSIC BLACK PHYLLITE IN THE EUREKA PEAK AREA CENTRAL BRITISH COLUMBIA*

(93A/7)

By Mary Anne Bloodgood

INTRODUCTION

The Eureka Peak area lies approximately 100 kilometres east of Williams Lake, in central British Columbia (Figure 3-2-1). Fieldwork in 1986 concentrated on establishing a stratigraphic order within the Triassic sequence of black phyllites and mapping the structural features of the area. An area of 300 square kilometres was examined, extending from Crooked Lake on the south, to the southeastern shore of Horsefly Lake on the north.

Previous work by the author during 1984, and briefly during the 1985 field season, involved detailed geologic mapping of the Eureka Peak syncline as part of a Master's thesis project under the direction of Dr. J. V. Ross.

GEOLOGIC SETTING

The area studied lies within the Quesnel terrane of the Intermontane Belt (Monger *et al.*, 1982), and is adjacent to the Omineca Belt-Intermontane Belt boundary. The terrane boundary is defined by the Eureka thrust (Struik, 1986). Structural relations across this major tectonic boundary have been summarized by Ross *et al.* (1985) and Ross and Fillipone (in preparation).

The unnamed black phyllites occur in a linear belt adjacent to the Omineca Belt-Intermontane Belt boundary and are assigned to the Quesnel River Group (Tipper, 1978; Campbell, 1978). The phyllites structurally overlie metavolcanic rocks to the north (Campbell *et al.*, 1973) that range in age from Mississippian to early Permian

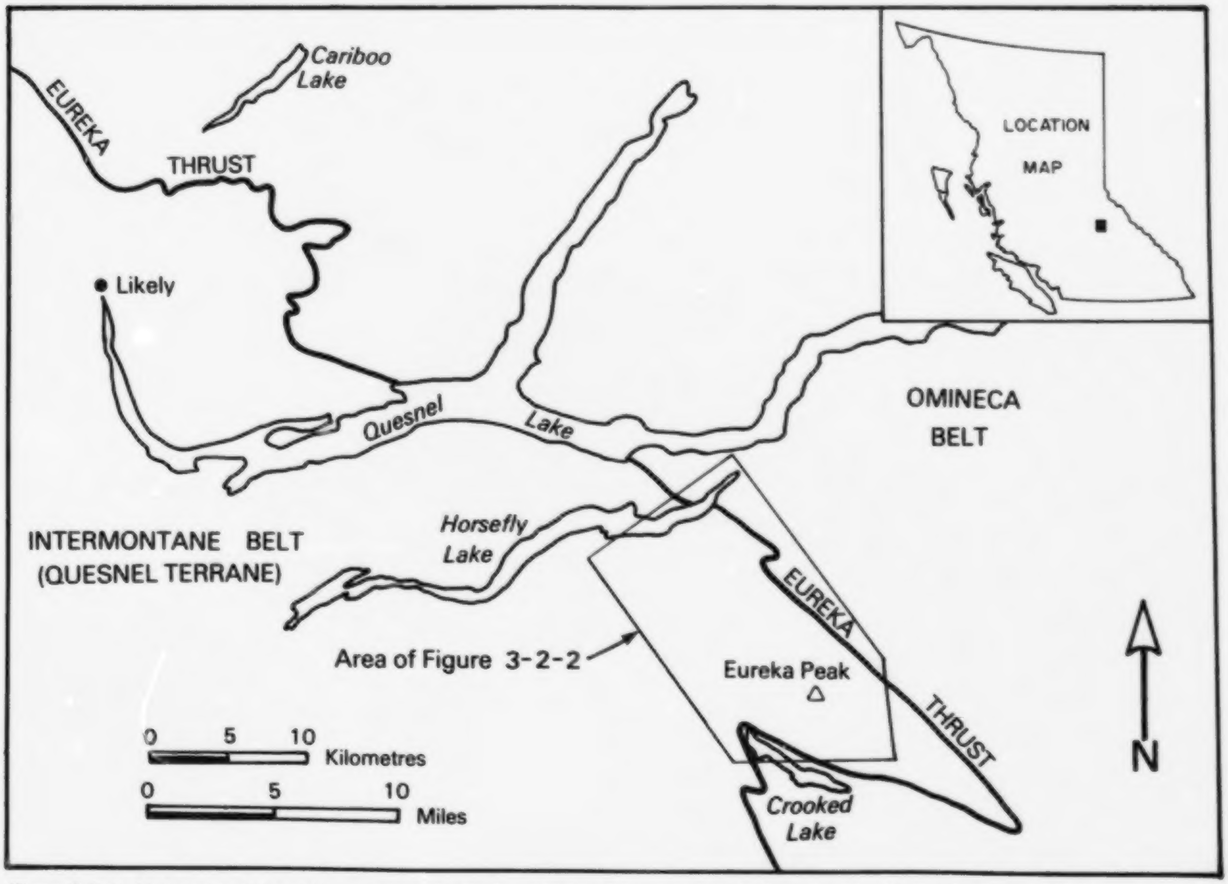
Cariboo Lake
EUREKA
THRUST
Likely
Quesnel
Lake
Horsefly Lake
INTERMONTANE BELT (QUESNEL TERRANE)
OMINECA BELT
EUREKA
THRUST
Area of Figure 3-2-2
Eureka Peak
Crooked Lake
0 5 10 Kilometres
0 5 10 Miles
N
LOCATION MAP

Figure 3-2-1: Major tectonic boundary between the Omineca Belt and Intermontane Belt outlined by the Eureka thrust. Location map inset.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

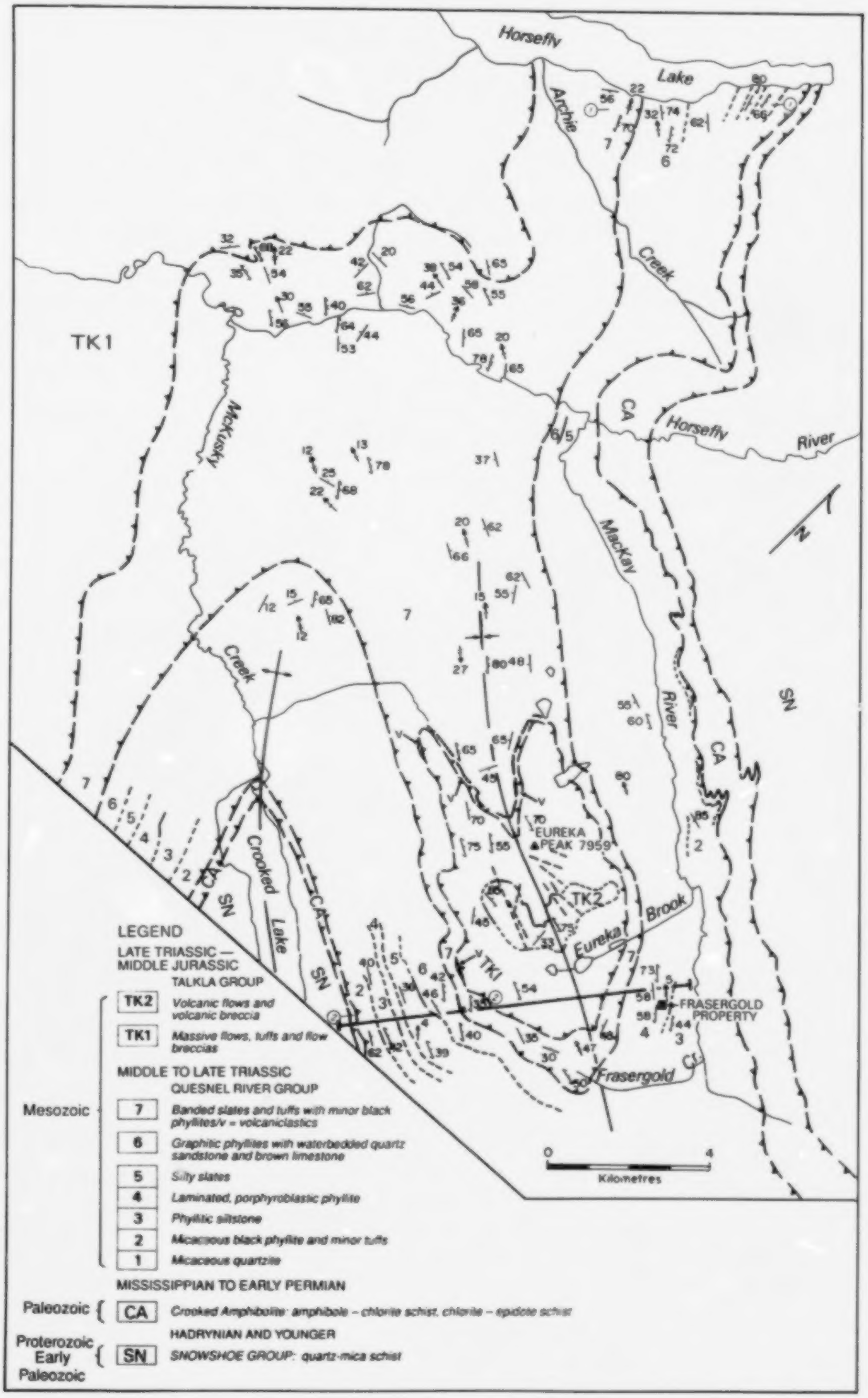
Horsefly
Lake
Archie
Creek
Horsefly
River
McKusky
Creek
MacKay
River
Crooked
Lake
Eureka
Brook
Frasergold
Cr.
EUREKA
▲PEAK 7959
FRASERGOLD
PROPERTY
TK1
TK2
TKI
CA
SN
N
0
4
Kilometres
LEGEND
LATE TRIASSIC — MIDDLE JURASSIC
TALKLA GROUP
TK2 Volcanic flows and volcanic breccia
TK1 Massive flows, tuffs and flow breccias
MIDDLE TO LATE TRIASSIC
QUESNEL RIVER GROUP
Mesozoic
7 Banded slates and tuffs with minor black phyllites/v = volcaniclastics
6 Graphitic phyllites with waterbedded quartz sandstone and brown limestone
5 Silty slates
4 Laminated, porphyroblastic phyllite
3 Phyllitic siltstone
2 Micaceous black phyllite and minor tuffs
1 Micaceous quartzite
MISSISSIPPIAN TO EARLY PERMIAN
Paleozoic
CA Crooked Amphibolite: amphibole – chlorite schist, chlorite – epidote schist
HADRYNIAN AND YOUNGER
Proterozoic Early Paleozoic
SN SNOWSHOE GROUP: quartz-mica schist

Figure 3-2-2: Generalized geology of the Eureka Peak area.

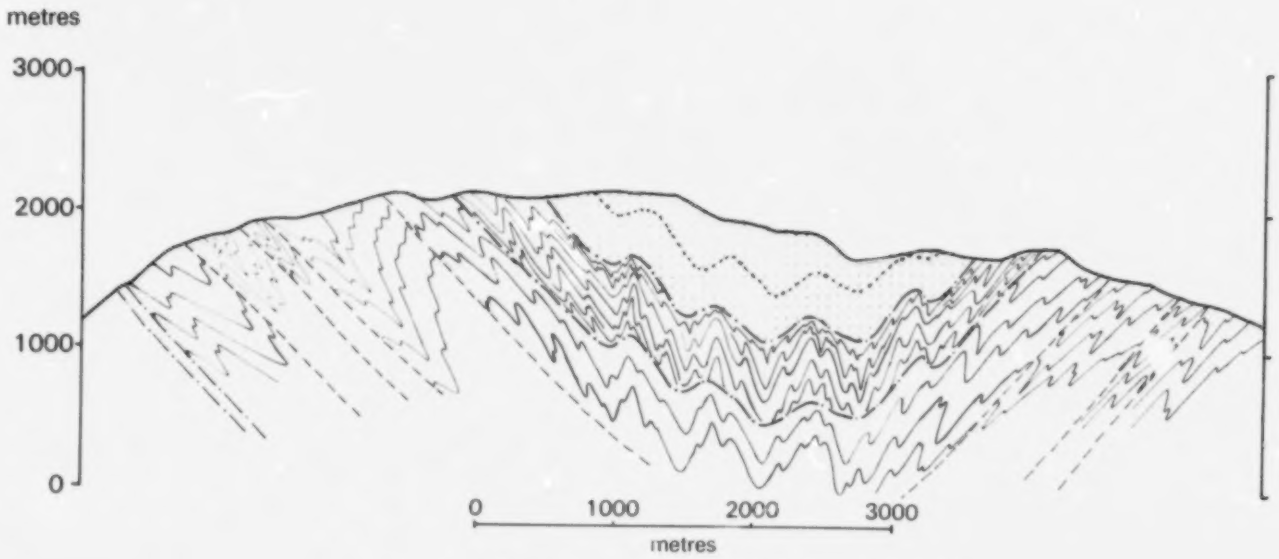
metres
3000
2000
1000
0
0
1000
2000
3000
metres

Figure 3-2-3: Schematic cross-section to accompany Figure 3-2-2.

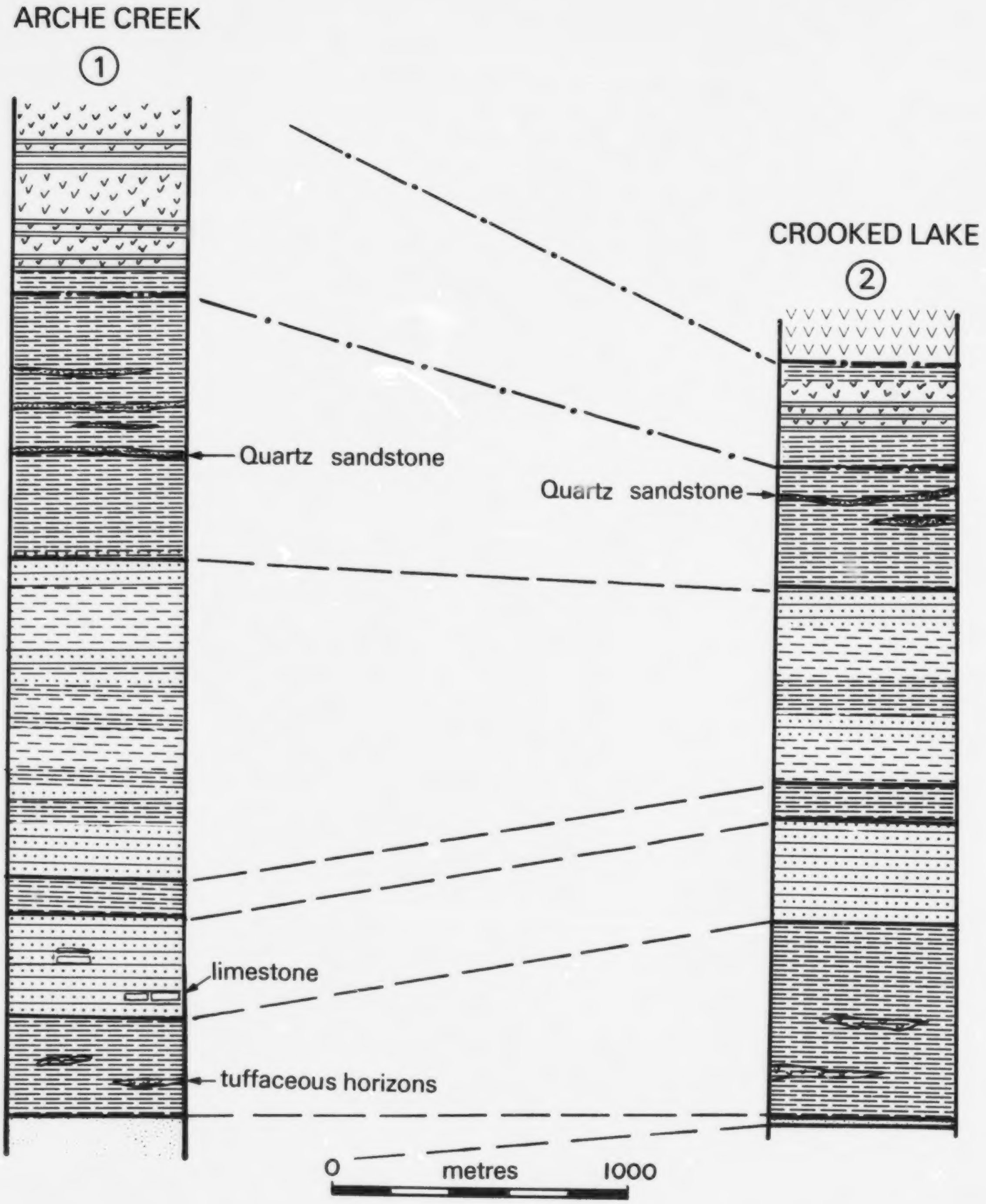
ARCHE CREEK
①
CROOKED LAKE
②
Quartz sandstone
Quartz sandstone
limestone
tuffaceous horizons
0
metres
1000

Figure 3-2-4: Schematic stratigraphic sections at two locations and correlations.

(Orchard and Struik, 1985). The metavolcanic unit in the Eureka Peak area is designated as the Crooked amphibolite and is believed to be correlative to the Antler Formation of the Slide Mountain Group exposed further to the north (Struik, 1986). The phyllites are in turn structurally overlain by metabasalts, tuffs and volcanic breccias of the Takla Group. Conodonts from limestone within the black phyllite north of Quesnel Lake range in age from early Middle Triassic (Anisian) to Late Triassic (Norian) (Struik, 1986). The age of the overlying Takla Group is unknown in the area studied, but may be Late Triassic to Early Jurassic and perhaps Middle Jurassic in age. These rock units have been deformed into a regional synformal structure referred to as the Eureka Peak syncline, and have been regionally metamorphosed to the lower greenschist facies.

STRATIGRAPHY

BLACK PHYLLITE (Lithologic Units 1-7)

Previous work in the Eureka Peak area during the 1985 field season established some details of the stratigraphy within the black phyllite package. Fieldwork in 1986 focused on establishing stratigraphic continuity throughout the map area. Areas of relatively continuous exposure were examined in detail and, where possible, measurements were made with reference to a known marker unit such as the lower contact with the Crooked amphibolite or the upper contact with the Takla Group rocks. Preservation of fine details of the original bedding features within the phyllites was essential to identifying stratigraphic variations. All contacts between defined lithologic units within the phyllites are gradational over a distance of several metres.

Two complete stratigraphic columns within the black phyllites were constructed and correlated (Figure 3-2-4). The location of each column is indicated on the accompanying geologic map (Figure 3-2-2).

UNIT 1

The basal unit of the black phyllite package is a micaceous quartzite of variable thickness (10 to 150 metres). The unit structurally overlies the metavolcanic rocks of the Crooked amphibolite. Buff to rust-weathering, pale recrystallized quartz sandstone dominates the unit. Locally the sandstones are dark grey to green in colour. Compositional layering is outlined by alternating quartz-rich and mica-rich bands. Planar alignment of muscovite defines the schistosity strongly developed parallel to bedding. The micaceous quartzite outcrops on both limbs of the Eureka Peak syncline. On the southern limb a maximum thickness of about 20 metres is observed; on the northern limb thickness varies from 20 to 150 metres (Elsby, 1985). Further to the northwest at Archie Creek a minimum thickness of 100 metres is exposed, however the contact with the underlying Crooked amphibolite is not observed.

Concordant and discordant relations have been observed along the contact between the quartzite and underlying metavolcanics. Imbrication of this contact has been documented on the southern limb of the syncline at the southeastern end of Crooked Lake (Campbell, 1971).

UNIT 2

An extremely siliceous, locally graphitic, dark grey to black phyllite overlies the micaceous quartzite. Bedding is difficult to discern and is locally defined by rust to dark grey-weathering thin quartz sandstone beds, minor dark grey siltstone beds up to 20 centimetres thick and discontinuous tuffaceous horizons and lenses. The phyllite observed at Archie Creek is more graphitic than its counterpart to the southeast at Crooked Lake. This unit is always characterized by a very shiny, phyllitic foliation.

UNIT 3

Unit 3 is comprised of a sequence of interbedded light and dark grey silty slates. Bedding is defined by well-developed fine banding and thin laminated quartz sandstone beds. The unit is nonfissile and has a well-developed slaty parting. Minor interbeds of dark grey siliceous limestone average 1 to 3 metres thick.

UNIT 4

A well-laminated grey phyllite, grading upwards into a porphyroblastic phyllite, overlies the silty slates of Unit 3. Bedding is defined by thin, finely laminated quartz sandstone beds. The strongly developed phyllitic foliation is locally outlined by fine graphitic material. Porphyroblasts of garnet, plagioclase and chloritoid occur within this unit on the southern limb of the Eureka Peak syncline. On the northern limb of the syncline, south of the MacKay River and also at Archie Creek, chloritoid occurs as porphyroblasts associated with a second porphyroblast phase which has been completely altered to an iron oxide.

UNIT 5

Graphitic phyllites interbedded with dark grey siltstones and silty slates overlie the porphyroblastic phyllite. Graphitic phyllite, blue-black in colour, comprises the majority of this unit at Archie Creek. To the southeast at Crooked Lake, silty slates are predominant and are only locally graphitic. Reddish brown weathering of laminated dark grey siltstone beds (10 to 15 centimetres), and pale green tuffs occurring as discontinuous lenses parallel to bedding are characteristic features of this unit. Very thin, laminated pale quartz sandstone beds occur locally throughout the unit.

UNIT 6

Unit 6 is a sequence of phyllites that grades upwards through graphitic black phyllites, grey silty phyllites and back into more graphitic black phyllites. Bedding is always well defined by pale, laminated siltstone beds. The prominently bedded siltstones rarely exceed 2 centimetres in thickness and are characteristic of this unit. In the uppermost portion of the unit, black silty limestones occur as lenses and discontinuous beds.

UNIT 7

Unit 7, the uppermost unit in the phyllite sequence, is readily distinguished by a significant volcanic component in the sediments. On the southern limb of the syncline the base of the unit is marked by a sharp fault contact; bedding attitudes are locally discordant across the fault (Plate 3-2-1). Quartz veins are prominent near the contact. This contact is not exposed at Archie Creek.

The volcanic component in the sediments increases progressively upwards. This stratigraphic progression is observed throughout the map area. Within the lowermost 50 metres of unit 7, dark grey to black phyllites are interbedded with grey to green tuffs. The tuffs become predominant upsection and are interbedded with grey to black banded slates, massive pale quartz sandstone and minor limestone. The uppermost 100 metres of the unit consists of fissile graphitic phyllites interbedded with tuffs and locally with dark brown to black limestones and minor quartz sandstone beds. In outcrop the phyllites are black and sooty, locally pyritiferous and recessive. The tuffaceous beds have a rusty, speckled appearance and are locally calcareous.

In the core of the Eureka Peak syncline and locally along the limbs, the top of the metasedimentary sequence is marked by a volcaniclastic unit of variable thickness. Where present the volcaniclastic unit is in fault contact with the overlying volcanic rocks of the Takla Group. The volcaniclastic unit and associated metasediments were earlier believed to stratigraphically and structurally overlie the volcanics (Campbell, 1971). These rocks are currently assigned to Unit 7 as the same stratigraphic gradation seen along the southern limb is also observed in the core of the Eureka Peak syncline, as the contact with the Takla Group is approached.

TAKLA GROUP

Basic volcanic rocks of the Takla Group occupy the core of the Eureka Peak syncline and are the youngest rocks exposed in the area. The volcanic succession consists of metabasalt, augite porphyry flows, tuffs and volcanic breccias. Low-grade metamorphism has affected the entire unit, resulting in the growth of chlorite, actinolite and rarely biotite. Throughout the area, the basal contact of the volcanics with the underlying metasediments is a fault.

STRUCTURE

Three major phases of deformation have been recognized. Overprinting relations observed in the field form the basis for differentiating each successive phase. Features associated with each phase are developed throughout the area, however the intensity and style of folding are influenced by lithology and position with respect to the regional structure.

PHASE 1

Phase 1 structures are primarily represented by folding of bedding (F_1). A well-developed penetrative slaty to phyllitic foliation (S_1) is axial planar to F_1 folds and moderately to steeply inclined to the northeast and southwest. A prominent mineral elongation lineation, parallel to the F_1 fold axes, plunges at shallow to moderate angles to the northwest and southeast.

The first phase structures show the greatest variation in style with respect to structural position. At lower structural levels the phase 1 folds are tight to isoclinal. The extreme tightness results in transposition of layering and local mesoscopic stratigraphic inversions. Transposition of Phase 1 structures is particularly pronounced within several tens of metres of the lower and upper contacts of the phyllite sequence with the Crooked amphibolite and Takla Group, respectively. At the contacts Phase 1 deformation has been largely accommodated by the phyllites, due to the contrast in competency between the units. The phyllite is less competent and the folding is controlled by the more rigid volcanic rocks. Without sedimentary "way-up" indicators it is impossible to determine the facing directions of individual transposed packages. Despite the local structural inversions there appear to be no overall stratigraphic inversions within the map area.

At higher structural levels the axial plane cleavage is more steeply inclined and the F_1 folds become more open and upright. In the Takla Group the first phase folds are open buckle folds.

PHASE 2

The second phase of deformation establishes the regional map pattern, folding the Omineca Belt-Intermontane Belt tectonic boundary. Phase 2 folds (F_2) refold all earlier structures throughout the area. A nonpenetrative spaced or crenulation cleavage (S_2), along which extensive pressure solution has occurred, is well-developed axial planar to F_2 folds. The second phase structures show a consistent southwesterly sense of vergence with their axial planes inclined steeply to the northeast. Phase 2 deformation is responsible for the tightening of first phase structures, locally overturning F_1 folds to the southwest. F_2 fold axes are oblique to nearly parallel fo F_1 axes and result in the curvilinear nature of F_1 linear structures. The similar orientation of the planar and linear elements

Plate 3-2-1: Sharp fault contact between Unit 6 and Unit 7. The light-weathering tuffs in the hangingwall distinguish Unit 7 from Unit 6.

within the two phases can be related to the general lack of intense refolding of F_1 structures, and instead has served to tighten F_1 folds that are then overprinted by the S_2 fabric.

PHASE 3

Phase 3 folds (F_3) occur as a warping of bedding and previously developed surfaces and locally as small-scale crenulations. The axial planar crenulation cleavage (S_3), where observed, dips to the southwest. F_3 folds are most evident at lower structural levels and display a consistent northeasterly sense of vergence. At higher structural levels, the effects of Phase 3 deformation are absent or only weakly developed.

PHASE 4

Phase 4 deformation is ubiquitous as a spaced cleavage and fracture set. Macroscopic folding is not associated with this latest structural episode. Spacing of fractures varies according to lithology, and ranges from about 1 centimetre to 0.5 metre; dips are steep to both the north and south.

FAULTING

Faulting associated with first phase deformation is particularly significant in the Eureka Peak area, where two major thrust faults have been identified:

(1) At the contact between Units 6 and 7.

(2) At the contact between Unit 7 and the overlying Takla Group.

The faults are nearly parallel to stratigraphic contacts, truncating bedding at low angles in some instances. They are overprinted by second phase structures, but are not intensely refolded. Brecciation, slickensides and quartz-filled fractures are common within the fault zones, which rarely exceed 3 metres in width (Plate 3-2-2). The amount of displacement along the thrusts is unknown.

Several higher angle faults cut the Takla Group rocks in the core of the Eureka Peak syncline. They are steeply inclined to the northeast and parallel the regional foliation; displacements are not significant.

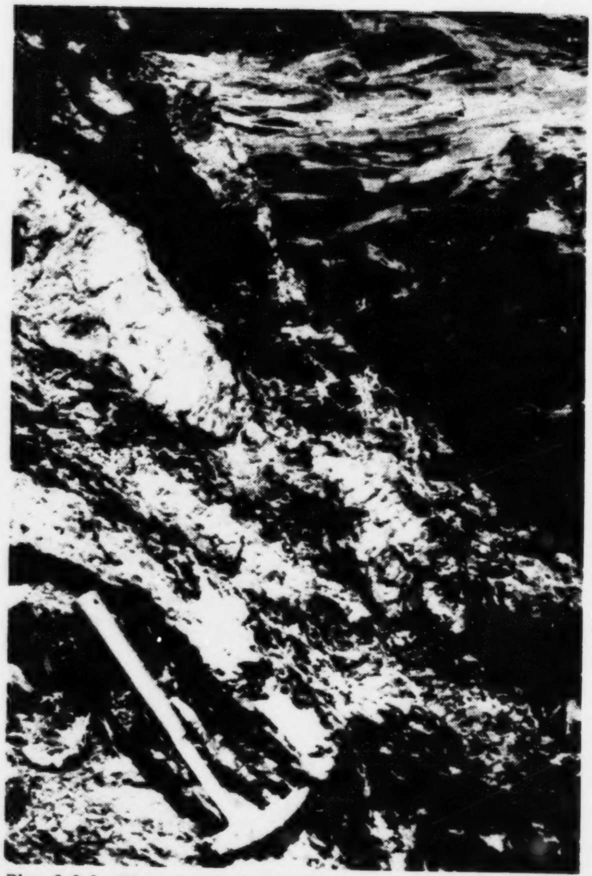

Plate 3-2-2: Discordant bedding relations observed across the fault zone within which occurs quartz-filled lenses and fractures.

MINERAL OCCURRENCES

The Frasergold property is located on the northeastern limb of the Eureka Peak syncline, southwest of the MacKay River (Figure 3-2-2). Gold mineralization is associated with pyrite, pyrrhotite and chalcopyrite, and occurs as disseminations in the black phyllite and in quartz veins. The mineralized zone is apparently localized in a porphyroblastic phyllite equivalent to Unit 4. Extensive mineralization of this unit is not apparent at Archie Creek or on the southern limb of the Eureka Peak syncline. Mineralized quartz veins parallel the phyllitic foliation (S_1), and are parallel to subparallel to bedding (S_0). The veins have been deformed, locally taking up a sigmoidal geometry. Quartz veins formed early in the structural history of the area and represent metamorphic segregations associated with the dewatering of the sediments during the initial stages of Phase 1 deformation. These processes are interpreted to be the result of deformation associated with convergence between allochthonous terranes and the western margin of North America during the mid-Jurassic. The mineralization is interpreted to be of syngenetic origin with later remobilization during regional metamorphism.

ACKNOWLEDGMENTS

I would like to acknowledge Dr. J.V. Ross of The University of British Columbia for initially suggesting the Eureka Peak area as a Master's degree project. His continued interest in the region and support of the project are greatly appreciated. Discussions with Jeffrey Fillipone have provided insights into the regional geology. His enthusiasm and expertise in the field are gratefully acknowledged. I would also like to thank Dr. A. Panteleyev for the opportunity to continue my studies in the Crooked Lake area.

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GEOLOGY OF SKOOKUMCHUCK MAP AREA SOUTHEASTERN BRITISH COLUMBIA (82G/13W)

By G. Carter and T. Höy

INTRODUCTION

The Skookumchuck area lies directly northeast of Kimberley and west of the Kootenay River in southeastern British Columbia (Figure 3-3-1). It measures approximately 18 kilometres by 28 kilometres, an area of about 500 square kilometres. Topographic elevations range from 760 metres in the east to 2320 metres in the west. It is all below timberline and, as a result, outcrops are often scarce. The area occupies the northwest corner of Leech's (1960) Fernie west half preliminary map. Regional mapping was initiated in 1982 by T. Höy and L. Diakow and was completed during the 1986 field season by G. Carter.

The Skookumchuck west half map sheet is underlain by Proterozoic Belt-Purcell rocks in the Purcell anticlinorium (Figure 3-3-2). Prior to this paper correlation between the Dutch Creek Formation in the Purcell Mountains to the west and northwest, and the Gateway, Phillips and Roosville stratigraphy to the south and southeast lacked documentation, and the exact extension of the underlying Nicol Creek lavas west of Skookumchuck was unknown.

The purpose of this paper is to clarify and describe the nature and thickness of upper Purcell rocks, to document the transition from Gateway, Phillips and Roosville stratigraphy into Dutch Creek stratigraphy, and to trace the extent of the Nicol Creek lavas.

GENERAL GEOLOGY

Figure 3-3-2 shows the general geology of the study area and of the immediately surrounding areas. The Skookumchuck area lies west of the Rocky Mountain Trench fault, north of the St. Mary fault and Sullivan deposit, and east of the White Creek batholith. The major structure in the area is a broad open anticline cut by several westerly dipping normal faults. The anticline exposes Proterozoic Belt-Purcell Supergroup rocks from the middle Aldridge to the Mount Nelson Formations (Figure 3-3-3).

LOCAL STRATIGRAPHY

Descriptions of lower Purcell rocks to the south and east have recently been published (Höy, 1979, 1983, 1985; McMechan, 1981) and are only briefly reviewed here. Upper Purcell rocks and, in particular, the nature of the transition from Gateway, Phillips and Roosville into Dutch Creek are described in considerably more detail. Stratigraphic thicknesses were measured in the field and calculated and estimated on cross-sections. The total thickness of the stratigraphic succession from the basal contact of the upper Aldridge to the Dutch Creek-Mount Nelson contact is about 10 000 metres (Figure 3-3-4).

LOWER PURCELL STRATIGRAPHY

The upper Aldridge member, exposed in the southwest corner of the map area, is about 500 metres thick (Section C-C', Figures 3-3-3 and 3-3-7). The overlying Creston Formation has been divided into three members (Figure 3-3-4). The lower silty member ($P\mathrm{C}c_1$) is about 700 metres thick, the middle quartzitic member about 1500 metres thick and the upper silty and quartzitic member has a thickness of about 500 metres. The total thickness of the Creston Formation is therefore about 2300 metres, compared with about 1600 metres in the Kimberley area (Höy, 1983), 2208 metres at Moyie Lake (Höy, 1985) and 1670 metres near Findlay Creek (Reesor, 1973). The overlying Kitchener Formation consists of a lower dolomitic siltstone member (±500 metres) and an upper dark grey carbonaceous dolomite and limestone member. The upper unit has conspicuous molar-tooth textures and is intruded, near its centre, by one or two gabbroic sills. The total thickness of the Kitchener Formation in the Skookumchuck area is approximately 2200 metres. To the west, near Cherry Creek, it is about 1430 metres thick (Reesor, 1958), east of the trench, 926 metres (Höy, 1985) and in the Kimberley area, approximately 2000 metres (Höy, 1983).

The Van Creek Formation has a variable thickness within the map area, but averages approximately 550 metres. It comprises laminated green siltstone and locally purplish sandstone. The Van Creek Formation is greater than 750 metres thick in the Bloom Creek area southeast of Cranbrook, and 926 metres thick at Cherry Lake, further south (*see* Sections 16 and 21 *in* Höy, 1985). West of the Skookumchuck area at Buhl Creek, Reesor (1958) measured 550 metres of Van Creek Formation. The formation is intruded by a dioritic sill near Ta Ta Creek.

The Van Creek is overlain by 60 to 130 metres of amygdaloidal basaltic volcanic flows of the Nicol Creek Formation. Near Echoes Lakes, Diakow (*in* Höy, 1985) described a polymictic conglomerate at the base of the Nicol Creek Formation which correlates with a similar conglomerate observed near Mount Baker, east of Cranbrook (Höy and Diakow, 1982). The conglomerate cuts down into the underlying Van Creek Formation, indicating the presence of a regional unconformity. The Nicol Creek lavas have been traced at regular intervals throughout the Skookumchuck area, from southwest of Reed Lakes (Figure 3-3-3) to the east bank of Bradford Creek (Section B-B', Figure 3-3-7.) The furthest previously recognized extent of Nicol Creek lavas was on Skookumchuck Creek, just west of Skookumchuck (Walker, 1926). This northwestern extension consists of two closely spaced flows separated by a thin sequence of fine tuffs and siltstone. A slightly younger sequence of thinly interbedded siltstone and lava 60 metres thick was recognized near Mount McMillan. Purple coarse sandstones have been encountered west of Bradford Creek at approximately the same stratigraphic level as the main lava flows. Further west on the ridge east of Buhl Creek, Reesor (1958) described 61 metres of volcanic tuff breccia and volcaniclastic rocks. The coarse purplish sandstones and basaltic tuffs indicate that the flows pinch out west of Bradford Creek, whereas tuffs extend over a somewhat larger area.

UPPER PURCELL STRATIGRAPHY

The upper Purcell stratigraphy comprises the Gateway, Phillips and Roosville Formations to the east, and the Gateway, Dutch Creek and Mount Nelson Formations to the northwest. A minimum of 1047 metres of upper Purcell rocks was measured near Echoes Lakes, whereas a minimum of approximately 3310 metres was estimated from map data and cross-sections near Larchwood Lake (Figure 3-3-5). Further thickening can be estimated from cross-sections to the northwest where the Dutch Creek Formation itself apparently reaches a thickness of over 4300 metres. A diagramatic

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British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

sketch (Figure 3-3-6) indicates the subsidence and dramatic thickening of the upper Purcell sedimentary package to the northwest.

The Dutch Creek has not been subdivided west and northwest of the study area, except near MacDonald Creek (Freiholz, 1984) and its facies and geometry are usually only poorly understood. Walker (1926) first described the formation and although he combined all of the upper Purcell strata below the Mount Nelson Formation into the Dutch Creek Formation, he still recognized a lower member which is correlative with the lower Gateway Formation. Reesor (1973) estimated about 1220 metres of Dutch Creek stratigraphy in a folded zone in the Lardeau east half map area. Near Rose Pass, to the southwest, Rice (1941) estimated about 1310 metres of Dutch Creek stratigraphy.

The eastern facies of the Gateway Formation has a north-south lithological continuity but thickens rapidly to the north, from 800 metres at Echoes Lakes to approximately 2400 metres at Larchwood Lake (Figure 3-3-5). The lower member of the formation is characterized by an assemblage of dominantly coarse-grained, quartz wackestone, often dolomitic and locally oolitic, and sandy dolomite. Light green laminated siltstone is commonly interbedded with coarse clastic and dolomitic packages. Massive stromatolitic dolomite, regularly interbedded with clean quartz wacke and quartz arenite, is more common toward the top of the lower Gateway. Recessive units throughout the formation usually consist of siltstone-argillite couplets. Scour and fill structures, ripple marks, crossbeds and less commonly salt casts are found in this member. The overlying upper Gateway is dominantly a silty unit that consists essentially of light green siltstone similar to siltstone in the lower unit, with lenticular layering and laminations as well as fine graded bedding. A thin unit of dark grey and black finely laminated siltstone and argillite is present slightly below the Phillips Formation. A similar microlaminite also occurs immediatly above the Phillips Formation. The lower Gateway is approximately 1800 metres thick at Echoes Lakes and about 1500 metres at Larchwood Lake.

The northwestern facies are similar to, but thicker than the eastern facies. The lower member of the Gateway Formation is often well exposed and generally easily identifiable. Its upper contact has been traced on the map and cross-sections. It comprises cycles of rounded and locally gritty quartz wackestone, overlain by oolitic, stromatolitic, or massive dolomite. These cycles sometimes contain a few thin purple argillite beds with mud cracks and locally, rip-up clasts. The cycles are overlain and interbedded with light green siltstone-argillite couplets, usually lenticular, laminated and graded. Paucity of outcrops, similarity of lithologies, and the absence of the overlying Phillips Formation make it difficult to determine the exact limit of the upper Gateway and the base of the overlying Roosville Formation. A lithologically similar unit has been recognized at MacDonald Creek in the Windermere area 46 kilometres to the northwest (unit 16 of Freiholz, 1984) indicating the extensive lateral extent of the distinctive lower Gateway Formation.

The Phillips Formation is a regional marker, recognized throughout the western Rocky Mountains. It is characterized by thin-bedded, maroon quartz siltstone, quartz wackestone and argillite. Ripple marks, cross-laminations and mud cracks are common sedimentary structures, and micaceous siltstone and argillite beds are diagnostic. It cannot be traced north of Larchwood Lake where it suddenly disappears. This discontinuity is attributed to a facies change that is probably related to subsidence in late Purcell time, as indicated by dramatic thickening of the underlying units. In the last recognized exposures of the Phillips Formation at Larchwood Lake, the maroon colouring is not as conspicuous as in exposures to the south and is restricted to specific beds. The Phillips Formation is underlain by several beds of white quartz arenite and quartz wacke. It is significant that the overlying Roosville Formation here has fewer beds with rip-up clasts and that these are now dominantly rounded rather than angular.

The Roosville Formation at Echoes Lakes has very distinct lithologies. A sequence of black siltite-argillite microlaminites underlies green siltstone beds with spectacular fine and coarse rip-up clasts, well-preserved mud cracks and graded bedding. Interbeds of dark oolitic dolomite appear towards the top of the exposed sequence and beds with rip-up clasts become rare. The northernmost exposures of beds with rip-up clasts in the Roosville Formation are seen further north at Larchwood Lake. Oolitic dolomite interbeds are common within light green and grey siltstone-argillite of the upper part of the Roosville Formation. Locally, lenses and pods of dolomite produce a conspicuous buff-weathering pattern in an otherwise light green-grey-weathering siltstone sequence. On the east slope of Lookout Mountain silty quartzite and oolitic or stromatolitic dolomite beds interbedded with green siltstone form the upper part of the Roosville Formation.

The upper part of the Dutch Creek Formation is discontinuously exposed north of Skookumchuck Creek. A carbonate marker bed approximately 200 metres thick occurs within the Dutch Creek Formation approximately 3000 metres above the Nicol Creek lavas. It has been mapped west of Sundown Creek and forms a small ridge north of Skookumchuck Creek. It is a massive cream to tan-weathering, thick to medium-bedded dolomite and limestone unit. Crypto-algal features are present locally. The top and the base of the unit consist mainly of argillaceous silty dolomite. It is included within the Dutch Creek rather than the Mount Nelson Formation as the basal quartzite typical of the Mount Nelson is not exposed below it. Furthermore, green siltstone, black argillite and thin oolitic dolomite interbeds higher in the section probably correlate with similar facies in the Roosville at Larchwood Lake. However, since the Phillips is absent here, this part of the section is shown as upper Dutch Creek.

About 400 metres of the overlying Mount Nelson Formation is exposed at Lookout Mountain. It was originally described by Walker (1926) who traced it north to the Windermere area. It has a gradational contact with the underlying Dutch Creek Formation; phyllitic black argillite-siltstone rocks become increasingly more quartzitic and the interbeds of quartz wacke become cleaner upsection. The basal quartzite of the Mount Nelson is a clean, well-rounded and well-sorted, medium-bedded orthoquartzite. It contains a few thin beds of sandy dolomite. The basal quartzite is overlain by a mixture of white, green and purple quartz arenite and dolomitic sandstone, locally gritty, as well as some purplish dolomite and argillite. Locally, the diagenetic character of these maroon beds is clearly demonstrated as the colouring crosscuts bedding planes and leaves spotty remnants of light green argillite. A buff-weathering sequence of dolomite overlies these quartz wacke, siltstone and argillaceous dolomite beds. This package is overlain by more green siltstone, and minor purple siltstone and argillite.

The section at Lookout Mountain beneath the Mount Nelson Formation is abnormally thin, due either to structural truncation or to initial deposition above a tectonic high. Alternatively, it is possible that the Mount Nelson Formation at Lookout Mountain correlates with the approximate stratigraphic position of the marker carbonate unit within the upper Dutch Creek further west. However, this is unlikely as the basal Mount Nelson quartzites are not recognized lower in the section.

STRUCTURAL GEOLOGY

Leech (1958b) briefly summarized the structure of the area: "The main structure on the west flank [of the Rocky Mountain Trench] is an anticline that plunges northward at about 25 degrees and whose limb becomes increasingly steep as it goes south." Structures are well illustrated by cross-sections A-A', B-B' and E-E' in Figure 3-3-7, and the geological map in Figure 3-3-3. In the northern part

TABLE 3-3-1. MINERAL OCCURRENCES IN THE SKOOKUMCHUCK WEST HALF MAP AREA

No.	Name	Commodities	Gangue	Type	Host
52	BBX	Au, Ag, Cu, Ba	Barite, quartz, siderite	Vein, shear	upper Dutch Creek Formation
64	Federal	Cu	Talcose material, limonite, pyrrhotite	Secondary enrichment sheared fault zone	lower Roosville Formation
65	McIntosh (Brenda)	Ag, Au, Cu, Ba	Barite, quartz, siderite	Vein, shear	upper Dutch Creek Formation
76	War Eagle	Co, Ni, Cu	———	———	Kitchener Formation
77	Lead (location uncertain)	Ag, Pb, Zn, Au	———	Vein fractures	upper Roosville or lower Mount Nelson Formation — granitic sill contact

of the Skookumchuck map area, the regional structure is dominated by two anticlines separated by a faulted syncline called the "McIntosh fault".

Within the Skookumchuck area, folds are essentially concentric or parallel and the refraction cleavage or fan cleavage is observable on outcrops as well as on cross-sections. Poles to cleavage, plotted on an equal-area net (Figure 3-3-8) are distributed within an elongate cluster illustrating a refraction cleavage pattern. Cleavage-bedding intersection lineations produce a rather scattered pattern, but generally trend north. Due to the open style of folding, no domain produced a complete bedding pole πgirdle as only a limb or minor dragfolds are represented in each domain.

Northeast-trending normal faults (Figure 3-3-7) produce an apparent sinistral fault movement on the map. These faults dip steeply to the northwest, with the west side down-thrown. A minor strike-slip component may also produce the sinistral displacement. The largest of these faults, the Mather Creek fault, juxtaposes lower Kitchener rocks against middle Creston strata. Further northwest, the large normal displacement on the fault is accommodated by a set of small north-trending normal faults. Their position and sense of movement are known with confidence due to measured displacement of the Nicol Creek lavas. Locally, the faults are marked by a zone of intense, coarse hematitic alteration, most commonly displayed in the light green siltstone-argillite units of the Gateway Formation. Several regional thrust faults and listric reverse thrust faults merge to the south of the Canal Flats map sheet. One of them, the Buhl Creek fault, transects the northwest corner of the Skookumchuck map area and places lower to middle (?) Dutch Creek strata above upper Dutch Creek stratigraphy. Further west, the "Copper Lake" thrust fault carries an overturned package of Creston to lower Dutch Creek (?) stratigraphy over Dutch Creek rocks. Stratigraphic and structural interpretation north of 50°N latitude are based on Leech's (1958a) map and Foo's (1979) study (Section A-A', Figures 3-3-3 and 3-3-7).

Structural deformation in the Skookumchuk area consists of several phases. Tilting, possibly associated with penecontemporaneous block faulting, occurred during or immediately following deposition of the Nicol Creek lavas and produced a low-angle regional unconformity. Movement along these block faults may have persisted through Gateway into Roosville time. Tilting also occurred after deposition of the Mount Nelson Formation; north of the study area, the Mount Nelson Formation has been irregularly eroded prior to deposition of the Hadrynian Toby Formation (Reesor, 1973; Foo, 1979).

Broad open folding, in part controlled by stratigraphy and earlier fault structures, developed during the Columbian orogeny. The axial planes of these folds became the loci of northeast-trending normal faults. The latest deformation involved eastward thrusting and folding that is particularly prominent in the northwest part of the area.

MINERAL OCCURRENCES

Mineral occurrences are located on Figure 3-3-3 and tabulated in Table 3-3-1 above. Most are veins in shear zones. Data on these occurrences are from the British Columbia Ministry of Energy, Mines and Petroleum Resources MINFILE, augmented by visits during the course of mapping.

DISCUSSION

The upper Aldridge, Creston, Van Creek and Nicol Creek Formations of the lower Purcell succession, are readily traceable throughout the southern and western part of the Skookumchuck area. They are similar lithologically and in thickness to exposures to the south in the Kimberley and Cranbrook areas. The upper Purcell succession can be traced northward from the Kimberley map area to southwest of Skookumchuck. Apparent facies changes, generally subtle and taking place over long distances elsewhere in Belt-Purcell rocks, are dramatic and rocks subdivided into three formations to the south, the Gateway, Phillips and Roosville, have been lumped together as the Dutch Creek Formation (Walker, 1926). Detailed mapping and structural analyses indicate that this change is due to two factors: facies changes in upper Purcell rocks, the most prominent being the relatively abrupt transition of characteristic maroon siltstone and argillite of the Phillips Formation into green siltstone, which is similar to green laminated siltstone and argillite in both overlying Roosville and underlying Gateway Formations; and, a marked thickening of the Gateway succession.

Rocks correlative with the lithologically distinct lower Gateway can be recognized to the western limit of the map area, south of the Buhl Creek fault. The upper Gateway is not as distinctive; without the marker Phillips Formation it cannot be separated from the overlying Roosville and must therefore be included as part of the Dutch Creek Formation. North of the Buhl Creek fault, Purcell rocks are totally isolated within thrust panels and upper Purcell rocks, lacking diagnostic marker units, are called the Dutch Creek Formation. However, it is probable that detailed mapping in the southwestern Canal Flats area would permit further subdivision of Dutch Creek rocks here as well.

The Mount Nelson Formation lies with a gradational contact on Roosville rocks on Lookout Mountain. Restored sections can only accommodate a considerably thinner upper Purcell succession beneath the Mount Nelson here. It is possible that a tectonic break has removed part of this succession but, as it could not be recognized in the field, it has not been shown on the map or cross-sections. This suggests that upper Purcell rocks here were deposited on a local tectonic high within the basin.

A simplistic model for deposition of upper Purcell rocks is illustrated in Figure 3-3-9. The thickening and related facies changes near Larchwood Lake suggest that foundering of the Purcell plat-

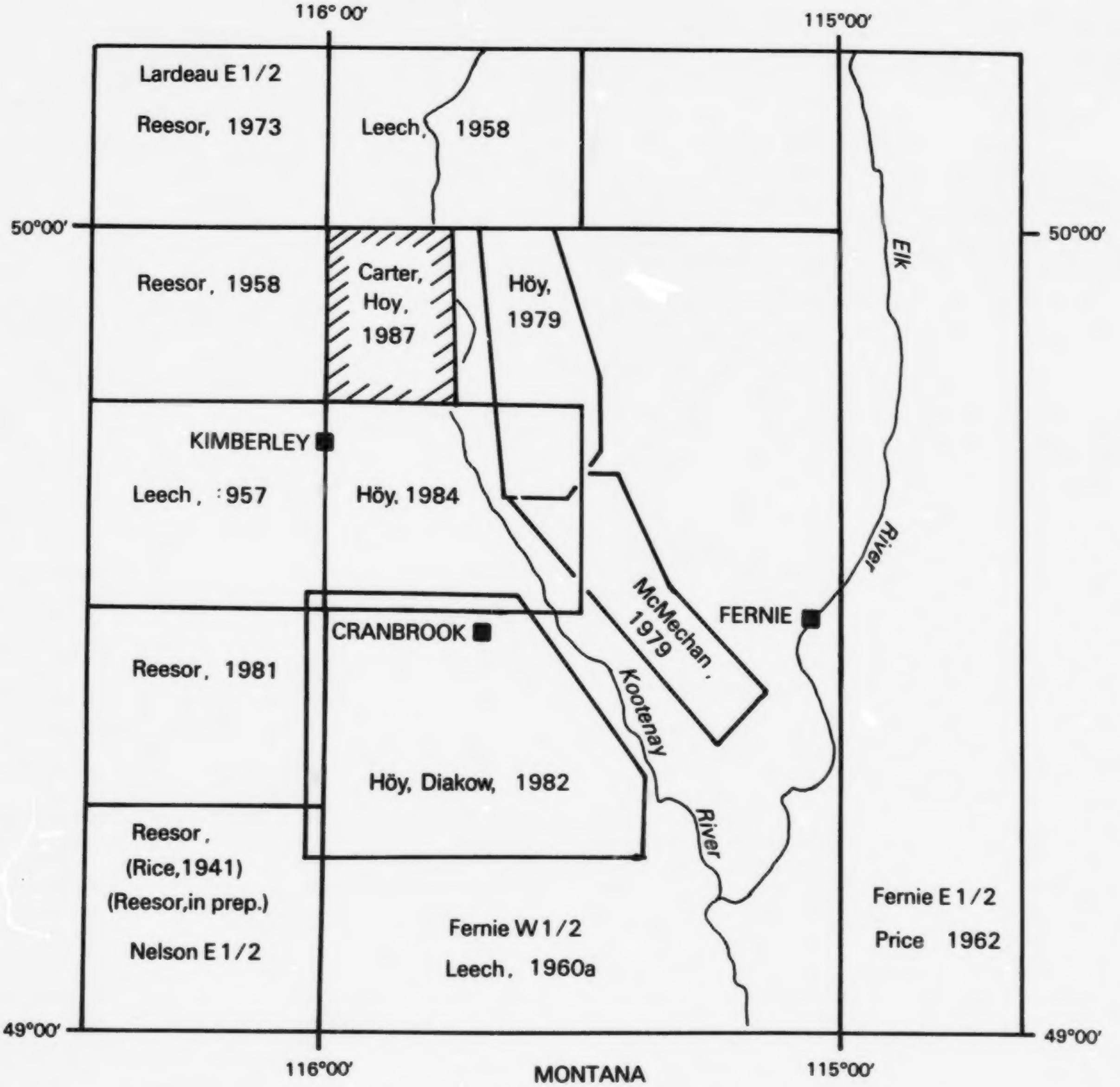
116° 00'
115°00'
50°00'
50°00'
49°00'
49°00'
116°00'
115°00'
MONTANA
Lardeau E 1/2
Reesor, 1973
Leech, 1958
Reesor, 1958
Carter, Hoy, 1987
Höy, 1979
KIMBERLEY
Leech, 1957
Höy, 1984
CRANBROOK
Reesor, 1981
Höy, Diakow, 1982
McMechan, 1979
FERNIE
Elk River
Kootenay River
Reesor, (Rice,1941) (Reesor,in prep.)
Nelson E 1/2
Fernie W 1/2
Leech, 1960a
Fernie E 1/2
Price 1962

Figure 3-3-1. Location map showing published geological maps in the vicinity of the Skookumchuck area.

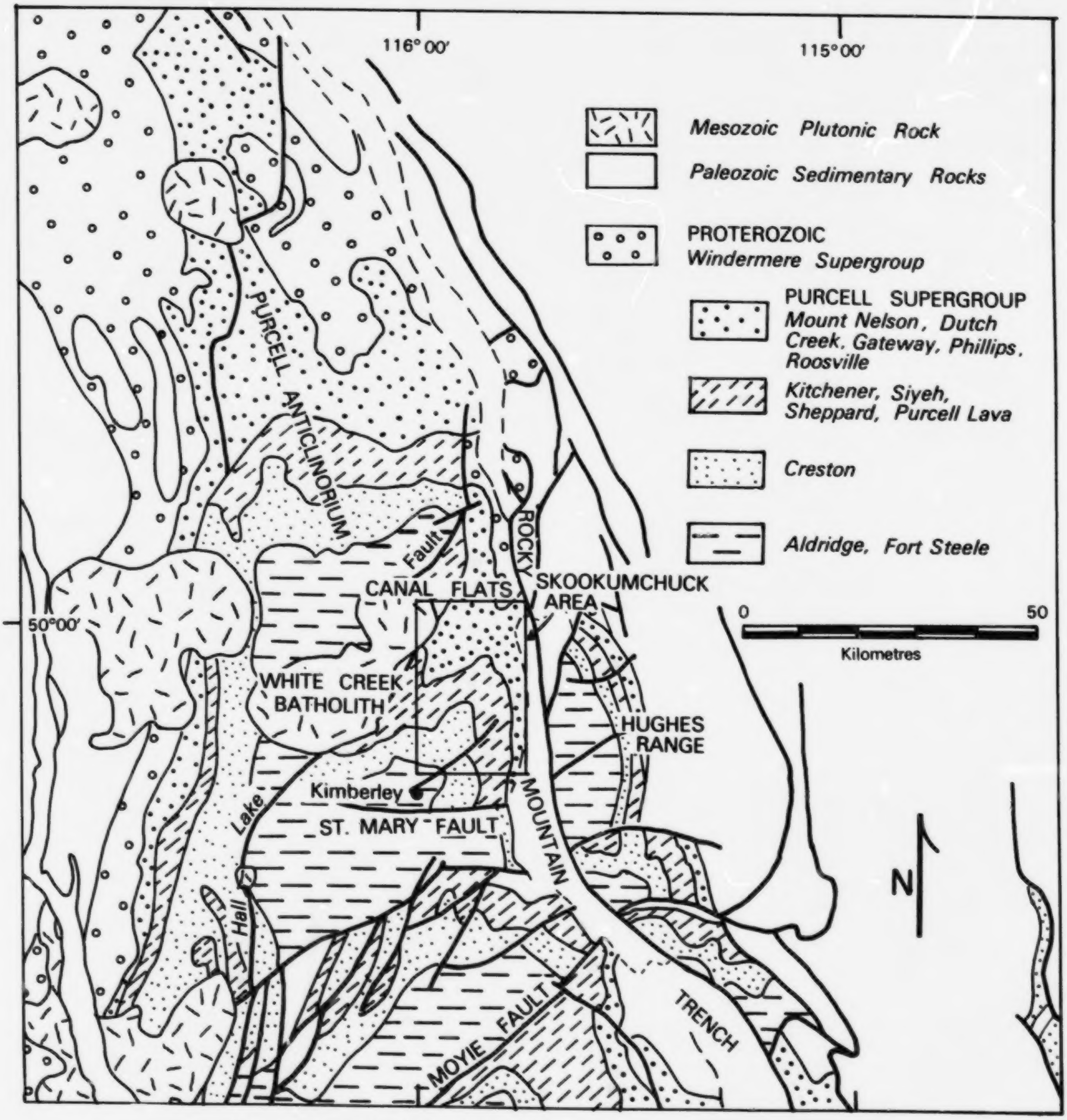
116° 00′
115° 00′
50°00′
Mesozoic Plutonic Rock
Paleozoic Sedimentary Rocks
PROTEROZOIC
Windermere Supergroup
PURCELL SUPERGROUP
Mount Nelson, Dutch Creek, Gateway, Phillips, Roosville
Kitchener, Siyeh, Sheppard, Purcell Lava
Creston
Aldridge, Fort Steele
0
50
Kilometres
N
PURCELL ANTICLINORIUM
Fault
ROCKY
CANAL FLATS
SKOOKUMCHUCK AREA
WHITE CREEK BATHOLITH
HUGHES RANGE
Kimberley
Lake
Hall
ST. MARY FAULT
MOUNTAIN
TRENCH
MOYIE FAULT

Figure 3-3-2. Regional geological map showing location of Skookumchuck area.

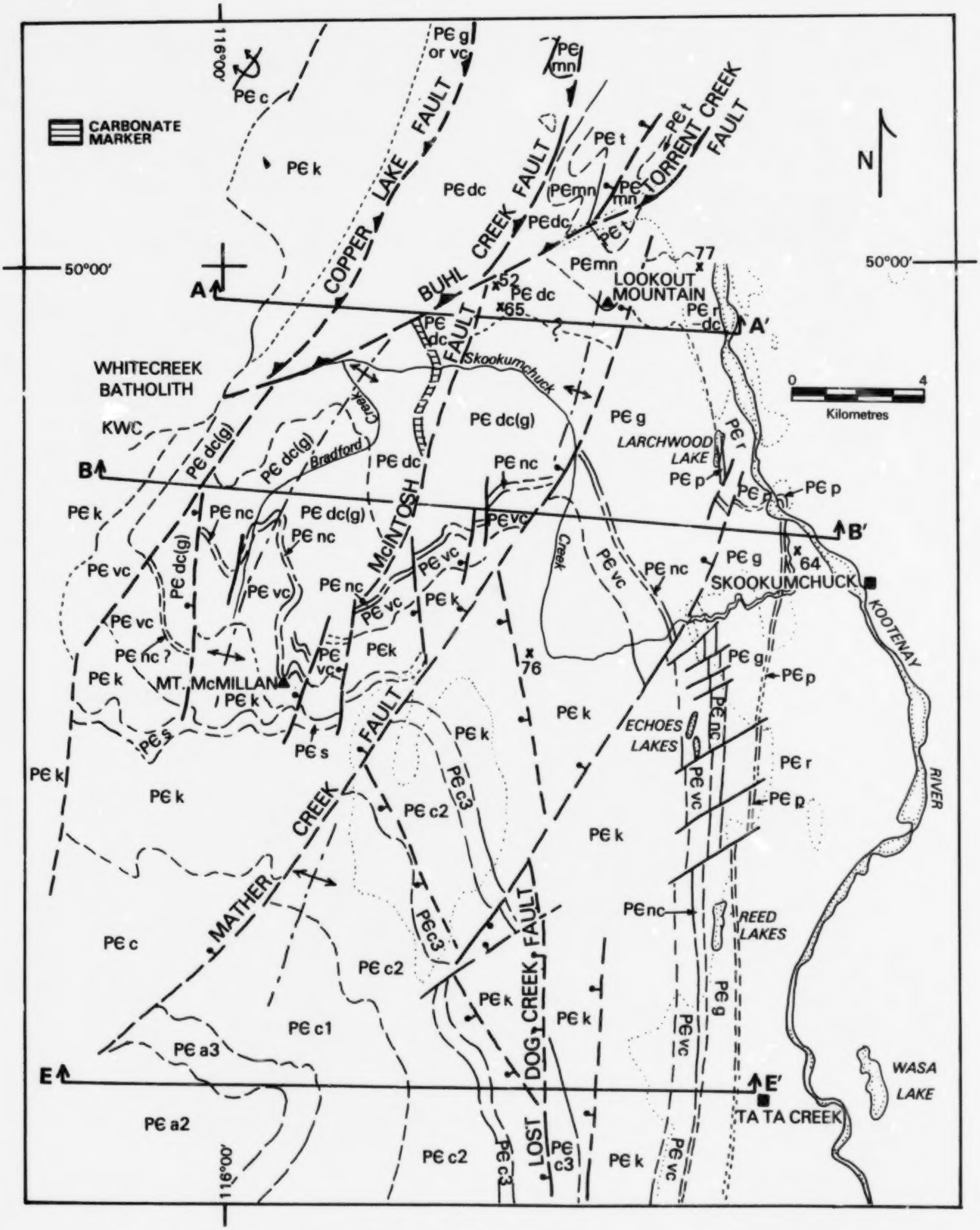
CARBONATE MARKER
N
116°00'
50°00'
Kilometres
0
4
COPPER LAKE FAULT
BUHL CREEK FAULT
TORRENT CREEK FAULT
BUHL FAULT
McINTOSH FAULT
MATHER CREEK FAULT
LOST DOG CREEK FAULT
WHITECREEK BATHOLITH
KWC
LOOKOUT MOUNTAIN
MT. McMILLAN
LARCHWOOD LAKE
ECHOES LAKES
REED LAKES
WASA LAKE
SKOOKUMCHUCK
TA TA CREEK
KOOTENAY RIVER
Skookumchuck
Creek
Bradford
A
A'
B
B'
E
E'
52
65
77
64
76
PЄ g or vc
PЄ mn
PЄ t
PЄ c
PЄ k
PЄ dc
PЄ r-dc
PЄ dc(g)
PЄ g
PЄ nc
PЄ p
PЄ r
PЄ vc
PЄ nc ?
PЄ s
PЄ c1
PЄ c2
PЄ c3
PЄ a2
PЄ a3

Figure 3-3-3. Geology of Skookumchuck area after G. Carter, T. Höy (this paper). Area north of 50°00'N modified after Leech (1958), Foo (1979); area west of 116°00'W modified after Reesor (1958); southwest corner modified after Paul Ransom (personal communication, 1986).

LEGEND

TERTIARY, PLEISTOCENE AND RECENT

⬚ *Unconsolidated sand and gravel*

MESOZOIC

CRETACEOUS

KWC *WHITE CREEK BATHOLITH*

PROTEROZOIC

HADRYNIAN

PЄt *TOBY FORMATION*

HELIKIAN

PURCELL SUPERGROUP

PЄs *Diorite sill/dyke*

PЄr *ROOSVILLE FORMATION*

PЄp *PHILLIPS FORMATION*

PЄg *GATEWAY FORMATION*

PЄnc *NICOL CREEK FORMATION (PURCELL LAVAS)*

PЄ vc *VAN CREEK FORMATION*

PЄk *KITCHENER FORMATION*

PЄc *CRESTON FORMATION*

- PЄc3 *Upper Creston*
- PЄc2 *Middle Creston*
- PЄc1 *Lower Creston*

PЄa *ALDRIDGE FORMATION*

- PЄa3 *Upper Aldridge*
- PЄa2 *Middle Aldridge*

PЄmn *MOUNT NELSON FORMATION*

PЄdc *DUTCH CREEK FORMATION*

SYMBOLS

Thrust Fault	▲ ▲
Normal Fault	⊥ ⊥
Strike-slip Fault	⇌
Prospect (see text)	x

form was probably due to block faulting which, in the Skookumchuck area, was concentrated near Larchwood Lake (Figure 3-3-9B). Initiation of block faulting was marked by the outpouring of basic flows and tuffs of the Nicol Creek Formation. The "high" in the vicinity of Lookout Mountain may be due to an uplifted block of lower Purcell rocks. The model implies that a number of the faults in the Larchwood Lake area (Figure 3-3-3) are early growth faults. These cut and offset Nicol Creek lavas but do not appear to continue through the Gateway into the overlying Phillips Formation. A number of these faults became the loci of late Mesozoic structures, including strike-slip faults and the prominent S-shaped fold northeast of Larchwood Lake.

Tectonic instability in late Purcell time was of a regional extent; Nicol Creek lavas are exposed along the entire eastern margin of the Purcell anticlinorium and western Rocky Mountains. Further evidence of instability includes the pronounced unconformity at the base of the Gateway Formation in the Cranbrook area (Höy and Diakow, 1982). Here the base of the Gateway is locally marked by a fluviatile conglomerate that cuts into the Nicol Creek Formation and removes the upper flows and underlying siltstone sequence.

CONCLUSIONS

The main conclusions of the study are summarized below:

(1) The Creston Formation has been subdivided into three informal members: a lower silty unit, a central quartzite-rich unit and an upper silty and quartzite unit.

(2) The Nicol Creek lavas can be traced throughout the Skookumchuck west half map area. They grade westward into basic tuffs and volcaniclastic rocks mapped by Reesor (1958).

(3) Individual formations in the upper Purcell succession can be traced northward to Skookumchuck Creek with little apparent facies or thickness changes.

(4) In the vicinity of Skookumchuck Creek, the upper Purcell succession thickens dramatically and facies changes are apparent; the most noticeable is a transition from maroon siltstone and argillite of the Phillips Formation into green siltstones of the Dutch Creek Formation.

(5) The Mount Nelson Formation at Lookout Mountain rests with a gradational contact on a relatively thin Dutch Creek succession.

(6) These relationships suggest that the tectonic instability, marked regionally by an outpouring of basic volcanics and locally by a pronounced unconformity was manifest in the Skookumchuck area by growth faults initiated in late to post-Nicol Creek time and continued active through Gateway time. Some of these early faults have been reactivated and are the loci of late faults and folds in the Larchwood Lake area.

ACKNOWLEDGMENTS

We wish to acknowledge Mike Fournier and Karen McDowell for their assistance during field mapping; their energy and enthusiasm were greatly appreciated. Larry Diakow is responsible for a considerable proportion of the mapping along the eastern edge of the map area, and Paul Ransom of Cominco Ltd. added considerably to our understanding of the southwest corner. The manuscript was improved considerably by the editorial comments of W.J. McMillan and J.M. Newell.

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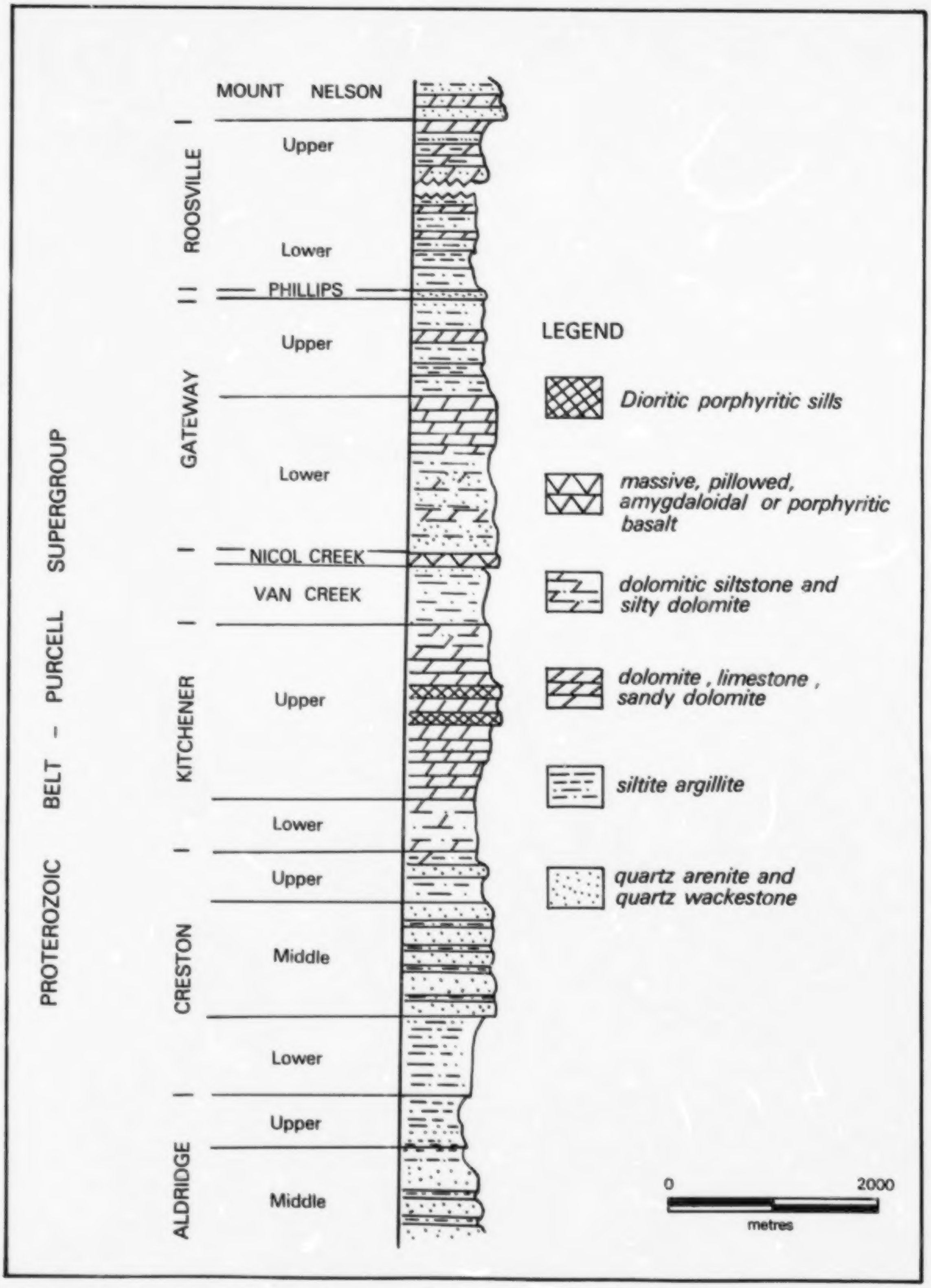
PROTEROZOIC BELT - PURCELL SUPERGROUP
MOUNT NELSON
ROOSVILLE
Upper
Lower
PHILLIPS
GATEWAY
Upper
Lower
NICOL CREEK
VAN CREEK
KITCHENER
Upper
Lower
CRESTON
Upper
Middle
Lower
ALDRIDGE
Upper
Middle
LEGEND
Dioritic porphyritic sills
massive, pillowed, amygdaloidal or porphyritic basalt
dolomitic siltstone and silty dolomite
dolomite, limestone, sandy dolomite
siltite argillite
quartz arenite and quartz wackestone
0
2000
metres

Figure 3-3-4. Generalized composite stratigraphic section of Skookumchuck map area; after Carter and Höy (this paper), Höy (1985), Leech (1960), Reesor (1958), Ransom (personal communication, 1986).

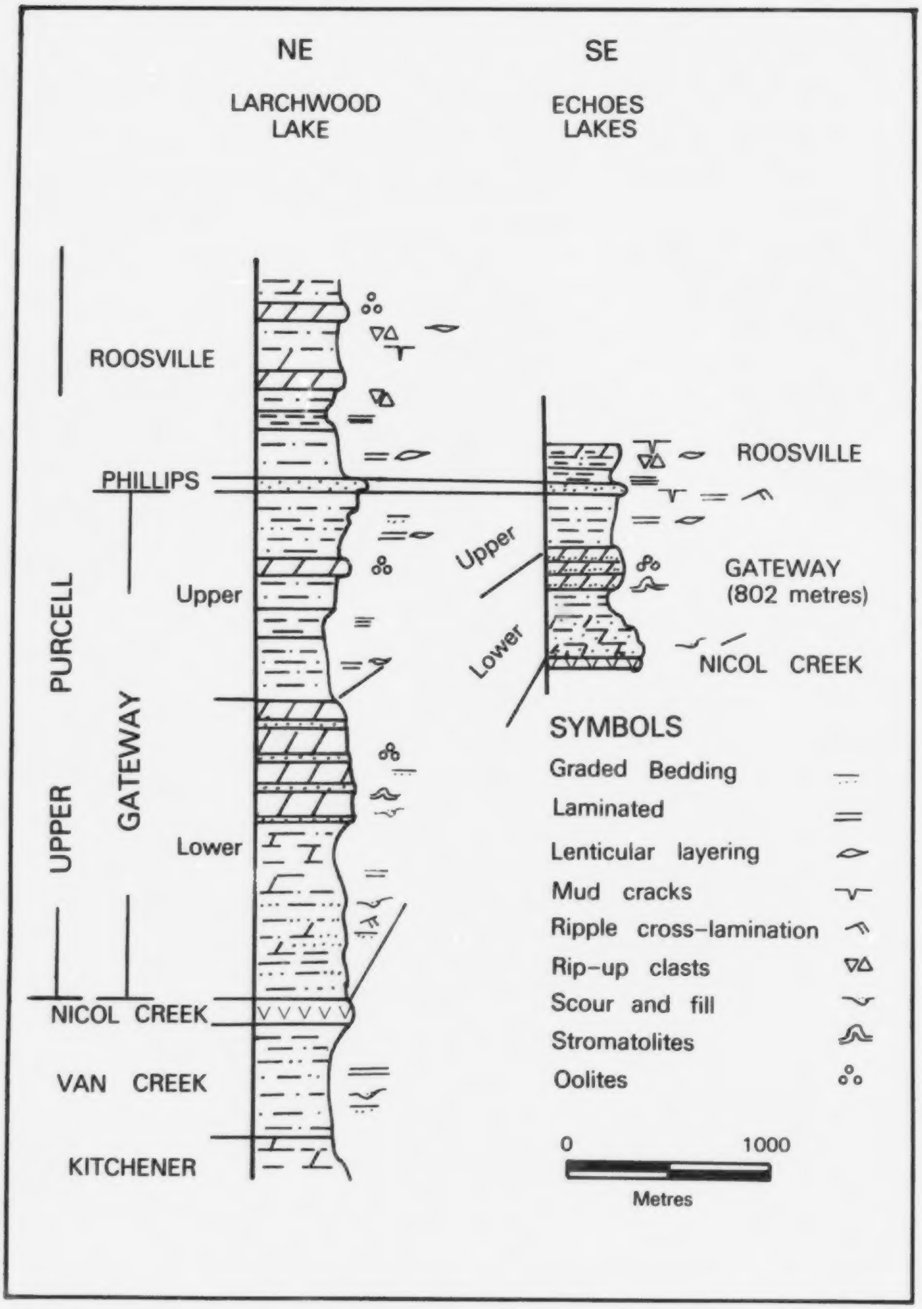
NE
SE
LARCHWOOD LAKE
ECHOES LAKES
ROOSVILLE
PHILLIPS
Upper
Lower
UPPER PURCELL
GATEWAY
NICOL CREEK
VAN CREEK
KITCHENER
ROOSVILLE
Upper
Lower
GATEWAY
(802 metres)
NICOL CREEK
SYMBOLS
Graded Bedding
Laminated
Lenticular layering
Mud cracks
Ripple cross-lamination
Rip-up clasts
Scour and fill
Stromatolites
Oolites
0
1000
Metres

Figure 3-3-5. North-south correlation of Gateway and Roosville formations as estimated near Larchwood Lake and measured near Echoes Lakes.

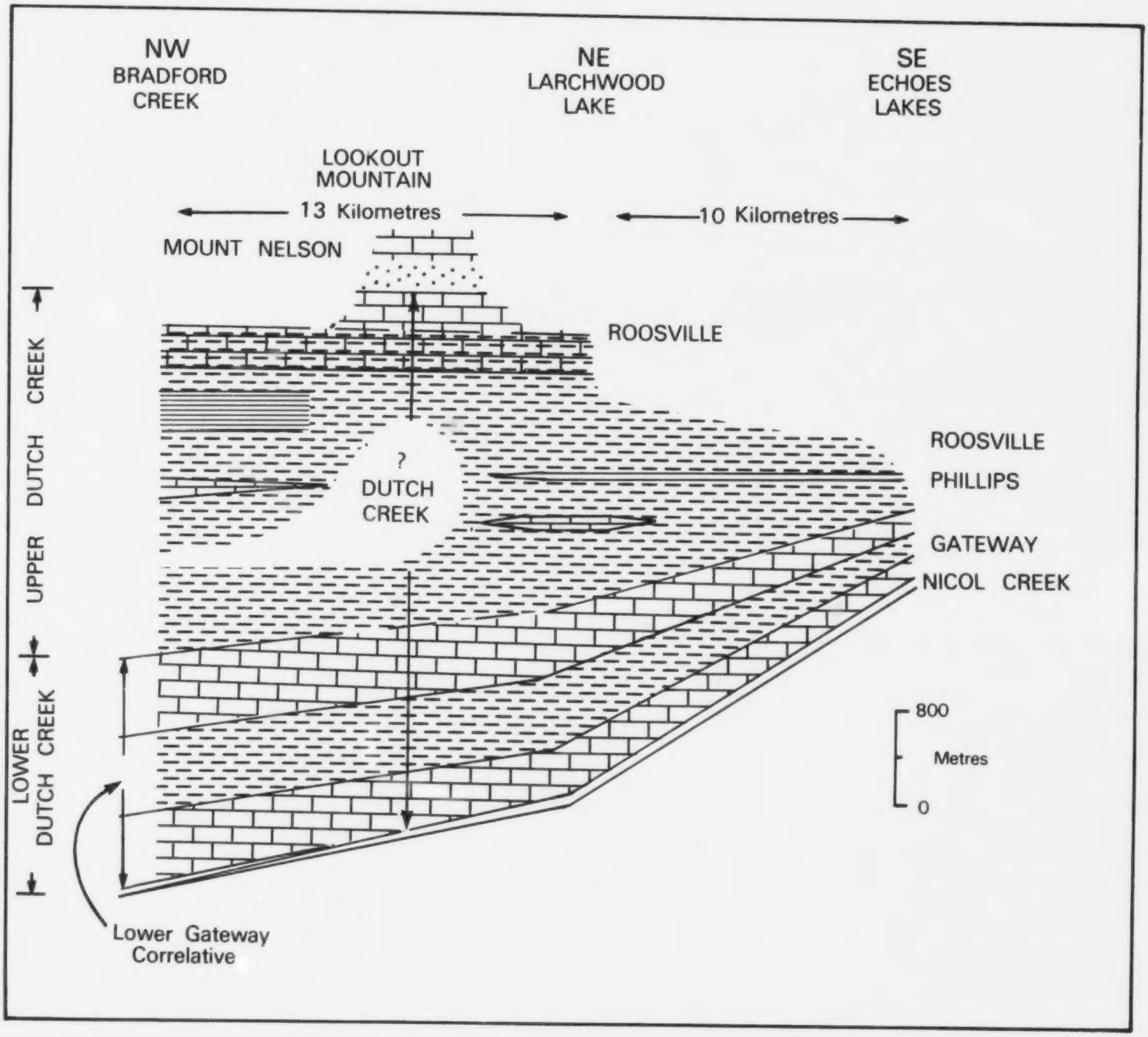
NW
BRADFORD CREEK
NE
LARCHWOOD LAKE
SE
ECHOES LAKES
LOOKOUT MOUNTAIN
13 Kilometres
10 Kilometres
MOUNT NELSON
ROOSVILLE
ROOSVILLE
PHILLIPS
GATEWAY
NICOL CREEK
?
DUTCH CREEK
UPPER DUTCH CREEK
LOWER DUTCH CREEK
800
Metres
0
Lower Gateway Correlative

Figure 3-3-6. Schematic northwest to southeast facies relationship of the upper Purcell Supergroup, Skookumchuck area.

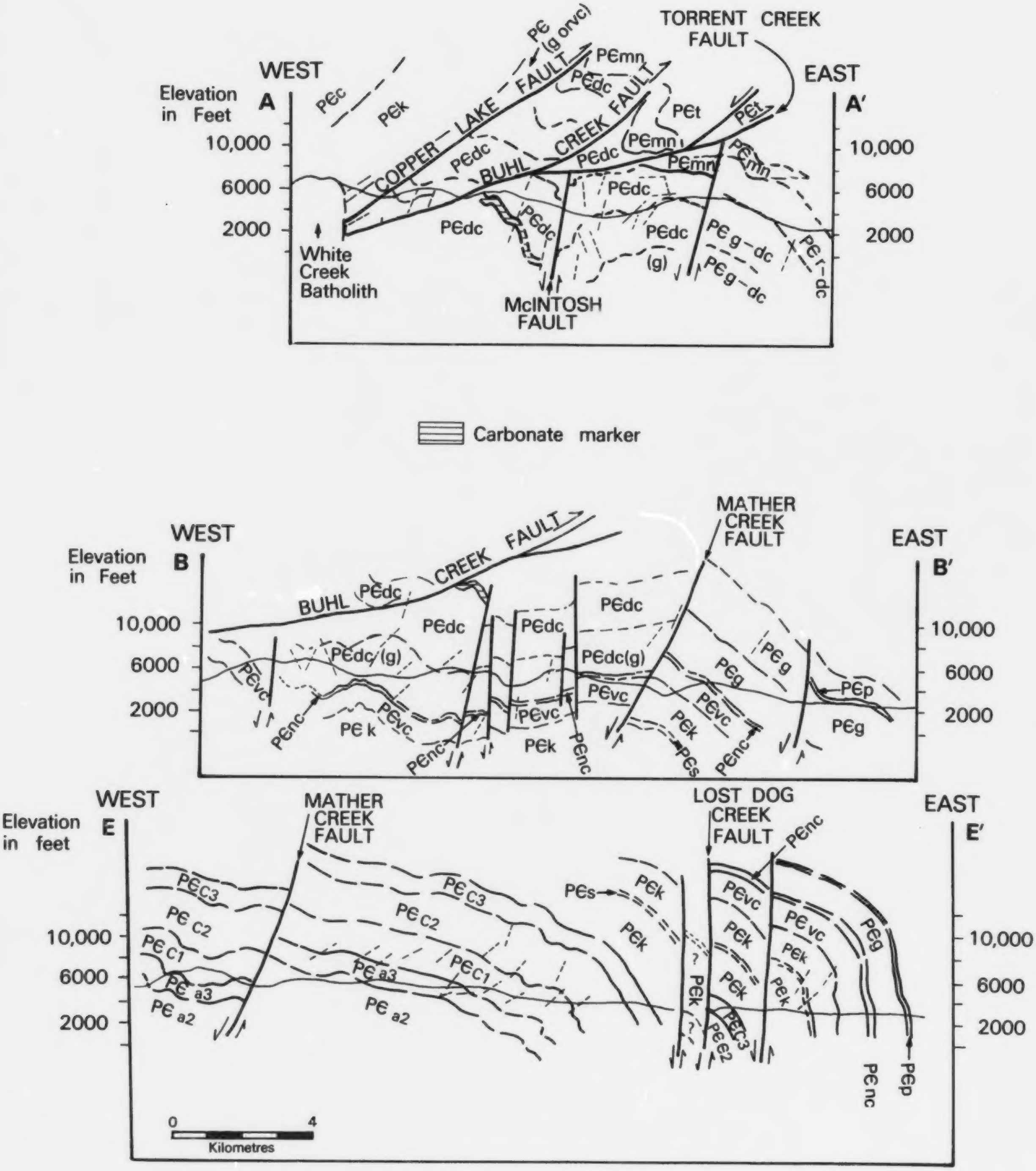
WEST
EAST
Elevation in Feet
A
A'
10,000
6000
2000
PЄc
PЄk
PЄ (g orvc)
PЄmn
PЄdc
TORRENT CREEK FAULT
COPPER LAKE FAULT
BUHL CREEK FAULT
PЄt
PЄdc
PЄmn
PЄg-dc
PЄr-dc
(g)
White Creek Batholith
McINTOSH FAULT
Carbonate marker
B
B'
BUHL CREEK FAULT
MATHER CREEK FAULT
PЄdc
PЄdc(g)
PЄvc
PЄnc
PЄk
PЄg
PЄp
PЄs
E
E'
Elevation in feet
MATHER CREEK FAULT
LOST DOG CREEK FAULT
PЄc3
PЄc2
PЄc1
PЄa3
PЄa2
PЄs
PЄk
PЄvc
PЄnc
PЄg
PЄp
?
0
4
Kilometres

Figure 3-3-7. Vertical cross-sections through Skookumchuck map area. Upper part of A-A' modified after Leech (1958), Foo (1979); western part of C-C' modified after Reesor (1958) and Paul Ransom (personal communication, 1986).

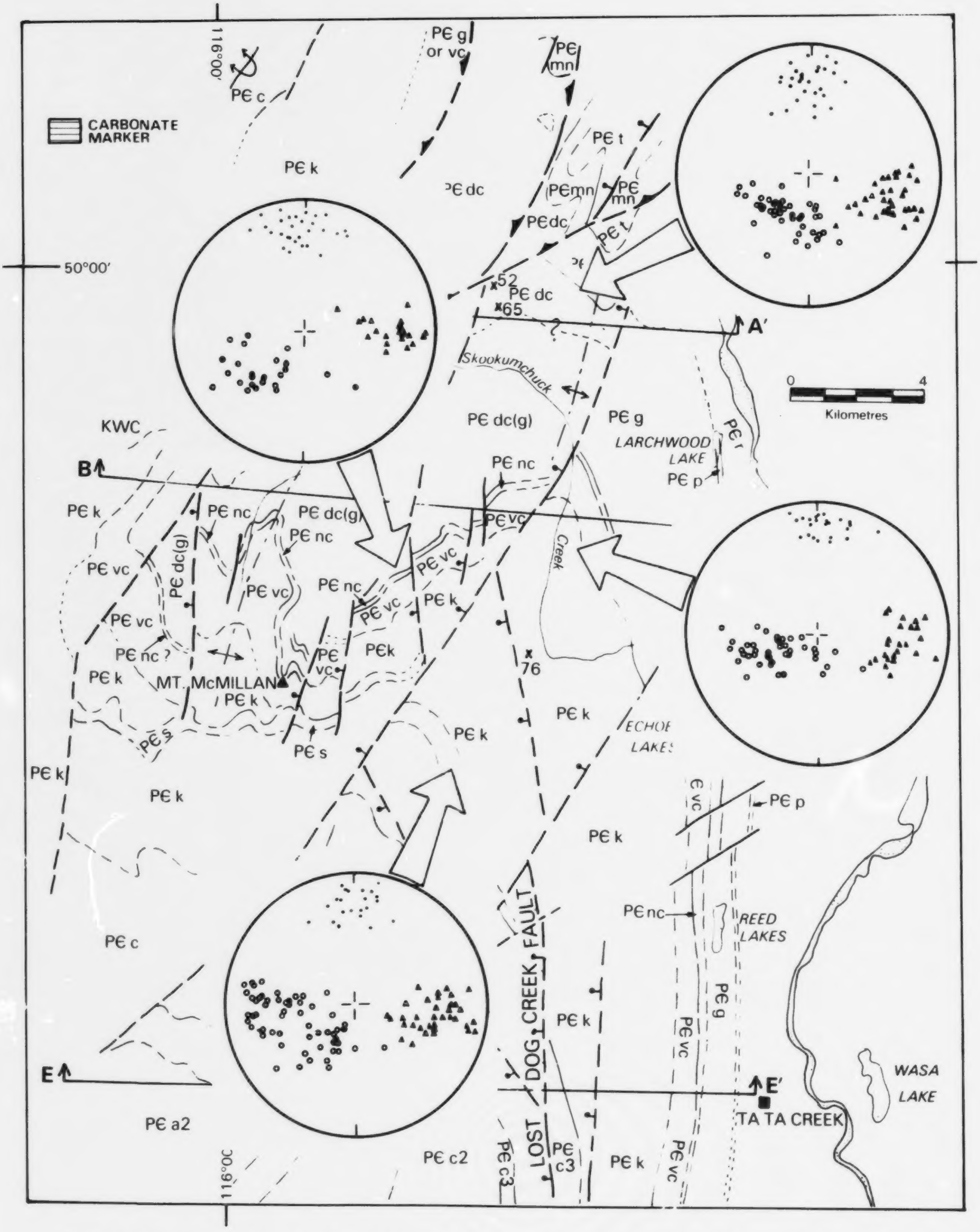
116°00′
PЄ g
or vc
PЄ
mn
PЄ c
CARBONATE
MARKER
PЄ k
PЄ dc
PЄ t
PЄmn
PЄ
mn
PЄdc
PЄ t
50°00′
52
PЄ dc
65
A′
Skookumchuck
PЄ dc(g)
PЄ g
0
4
Kilometres
KWC
LARCHWOOD
LAKE
PЄ nc
PЄ p
B
PЄ k
PЄ nc
PЄ dc(g)
PЄ nc
PЄ vc
PЄ dc(g)
PЄ vc
Creek
PЄ vc
PЄ nc
PЄ vc
PЄ vc
PЄ k
PЄ nc ?
PЄ
vc
PЄk
76
PЄ k
MT. McMILLAN
PЄ k
PЄ s
PЄ s
PЄ k
PЄ k
ECHO
LAKES
PЄ k
PЄ k
Є vc
PЄ p
PЄ k
PЄ c
FAULT
PЄ nc
REED
LAKES
DOG CREEK
PЄ g
PЄ k
PЄ vc
E
E′
WASA
LAKE
TA TA CREEK
PЄ a2
LOST
PЄ
c3
PЄ c2
PЄ c3
PЄ k
PЄ vc
116°00′

Figure 3-3-8. Distribution of lineations (dots), bedding poles (circles) and cleavage poles (triangles) for some of the domains of the Skookumchuck area, plotted on equal area stereonets.

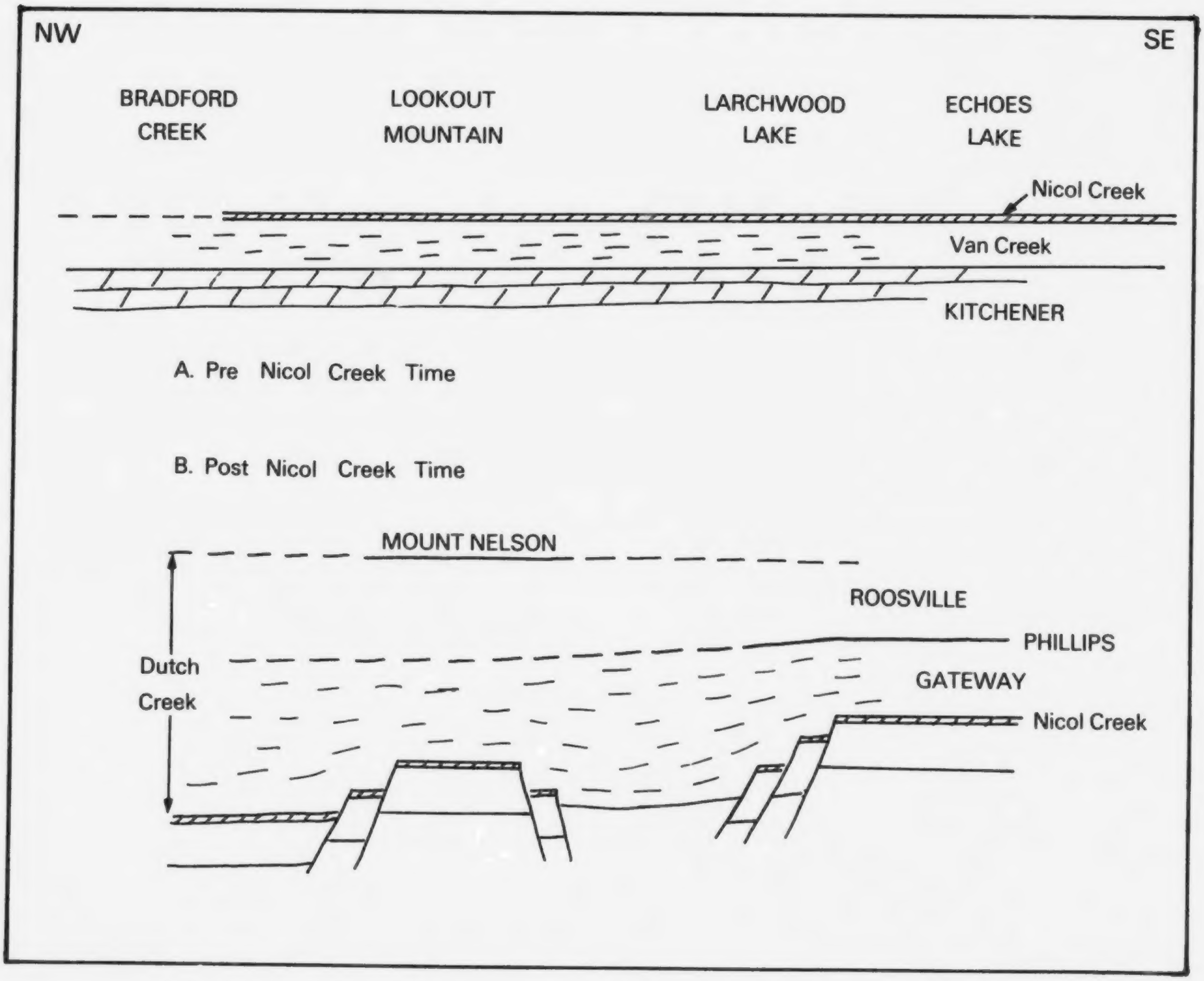
NW
SE
BRADFORD CREEK
LOOKOUT MOUNTAIN
LARCHWOOD LAKE
ECHOES LAKE
Nicol Creek
Van Creek
KITCHENER
A. Pre Nicol Creek Time
B. Post Nicol Creek Time
MOUNT NELSON
ROOSVILLE
PHILLIPS
GATEWAY
Nicol Creek
Dutch Creek

Figure 3-3-9. Postulated model for deposition of upper Purcell rocks, Skookumchuck west half map area.

GEOLOGY AND MINERAL POTENTIAL OF THE WARNER PASS MAP SHEET*
(92O/3)

By J. K. Glover and P. Schiarizza

INTRODUCTION

The Warner Pass map area is located 185 kilometres north of Vancouver on the northeastern margin of the Coast Mountains. It covers an area of 980 square kilometres within the Chilcotin Range, and is characterized by rugged mountains and glaciated U-shaped valleys; elevations vary from 1500 metres to over 3000 metres, with a treeline at about 1800 metres.

The sheet was mapped at a scale of 1:20 000 by a four-person field crew during the 1986 field season. Particular attention was paid to zones of alteration and mineralization; approximately 120 rock samples were collected for trace element analysis.

This report covers the first phase of a regional mapping program designed to be completed in four years and to provide 1:50 000-scale geological maps and mineral potential overlays to aid exploration in the Taseko-Bridge River area.

REGIONAL GEOLOGY

The study area is part of an extensive northwest-trending belt of Middle Triassic to Upper Cretaceous sedimentary and volcanic rocks along the northeast margin of the Coast Plutonic Complex (Figure 3-4-1). Middle Jurassic to Upper Cretaceous strata within this belt are thought to have been deposited in a narrow northwest-trending basin, the Tyaughton trough, that was bounded by intermittently uplifted and eroded landmasses to the northeast and southwest (Jeletzky and Tipper, 1968). This basin evolved from marine to nonmarine conditions in mid-Cretaceous time, during uplift of the Coast Mountain suprastructure to the southwest (Kleinspehn, 1985).

Tectonic reconstruction of the southern Canadian Cordillera indicates that the Tyaughton trough was once continuous with the Methow basin (Figure 3-4-1). It has been offset by at least 70 kilometres of right-lateral strike-slip movement along the north-trending Fraser-Straight Creek fault system during Late Cretaceous (?)-Early Tertiary time (Monger, 1985). Earlier, post-Albian fragmentation of the basin occurred along the northwest-trending Yalakom-Hozameen fault system, along which up to 175 kilometres of right-lateral offset has been postulated in the vicinity of the study area (Kleinspehn, 1985). The Yalakom fault crosses the extreme northeastern corner of the map area, from where it has been traced to the northwest, west of Taseko Lakes and into the Chilko Lake area (Tipper, 1969, 1978; McLaren, 1986).

Mesozoic strata of the Tyaughton trough are intruded by mid-Cretaceous quartz diorite to quartz monzonite of the Coast Plutonic Complex (McMillan, 1976) and by equigranular and porphyritic granitic stocks of probable late Cretaceous and Eocene age (Tipper, 1978); they are unconformably overlain by Eocene volcanic and sedimentary rocks and by Miocene basalt.

GENERAL GEOLOGY

Figure 3-4-2 shows the generalized geology of the Warner Pass map sheet. Stratified sedimentary and volcanic rocks have been divided into eight units on the basis of lithological characteristics. Previous mapping of the Taseko Lakes sheet (92O) by Tipper (1978) and regional correlations and biostratigraphy (Tozer, 1967; Jeletzky and Tipper, 1968) have been used to correlate these units, wherever possible, with regionally extensive and formally recognized stratigraphic units. Intrusive rocks shown in Figure 3-4-2 have been divided into four lithologically distinct suites. A limited amount of data from assessment reports has been incorporated into this map in order to supplement our field data.

The dominant structural trend in the area is northwesterly and is reflected by the major faults, folds, bedding attitudes and, in general, the margin of the Coast Plutonic Complex. Spectacular alteration zones, commonly associated with intrusive rocks and fault zones, are locally anomalous in gold and associated elements.

LITHOLOGY

SEDIMENTARY AND VOLCANIC ROCKS

UNIT 1

This unit is equivalent to the lower part of the Tyaughton Group and is of Norian (Upper Triassic) to Hettangian (Lower Jurassic) age (Tipper, 1978). It has a total thickness of 240 metres in a section exposed on the ridge northwest of Castle Peak, immediately east of the map area (Tozer, 1967, page 77,). This section is part of a structurally complex panel, located north of Tyaughton Creek, along the eastern margin of the map area. Here, Unit 1 comprises red-weathering interbeds of conglomerate with volcanic clasts, conglomeratic sandstone and sandstone at the base, overlain by light grey to buff-weathering, massive to thickly bedded limestone with corals. This is in turn overlain by limestone conglomerate with a sandy matrix. The upper part of the succession has a green-weathering grit with conglomeratic seams containing volcanic clasts, overlain by green sandstone containing *Cassianella lingulata* (the "Cassianella beds" of Tozer, 1967) and, at the top, green sandstone and conglomeratic sandstone with pebbles of volcanic rock. In the Castle Peak area, 2.5 kilometres to the east, these uppermost beds contain ammonites of latest Triassic and earliest Jurassic age (H.W. Tipper, personal communication, 1986).

A small klippe, comprising upright, crossbedded grey-green sandstone and conglomeratic sandstone of probable Unit 1, occurs at the top of the cliffs east of Lorna Lake (Figure 3-4-2), where it structurally overlies an overturned turbidite sequence assigned to Unit 2.

UNIT 2

This unit is thought to be equivalent to the basal part of the Relay Mountain Group, designated as Middle Jurassic (mid-Callovian (?) to Lower Oxfordian) by Jeletzky and Tipper (1968, page 14,) who estimated its thickness to be 300 to 600 metres. Northeast of Tyaughton Creek it is dominated by recessive, dark grey to black shales with minor thin siltstone and reddish brown, internally laminated calcarenite interbeds. Thin to medium-bedded greywacke, grit and pebble conglomerate containing aphanitic felsic volcanic

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

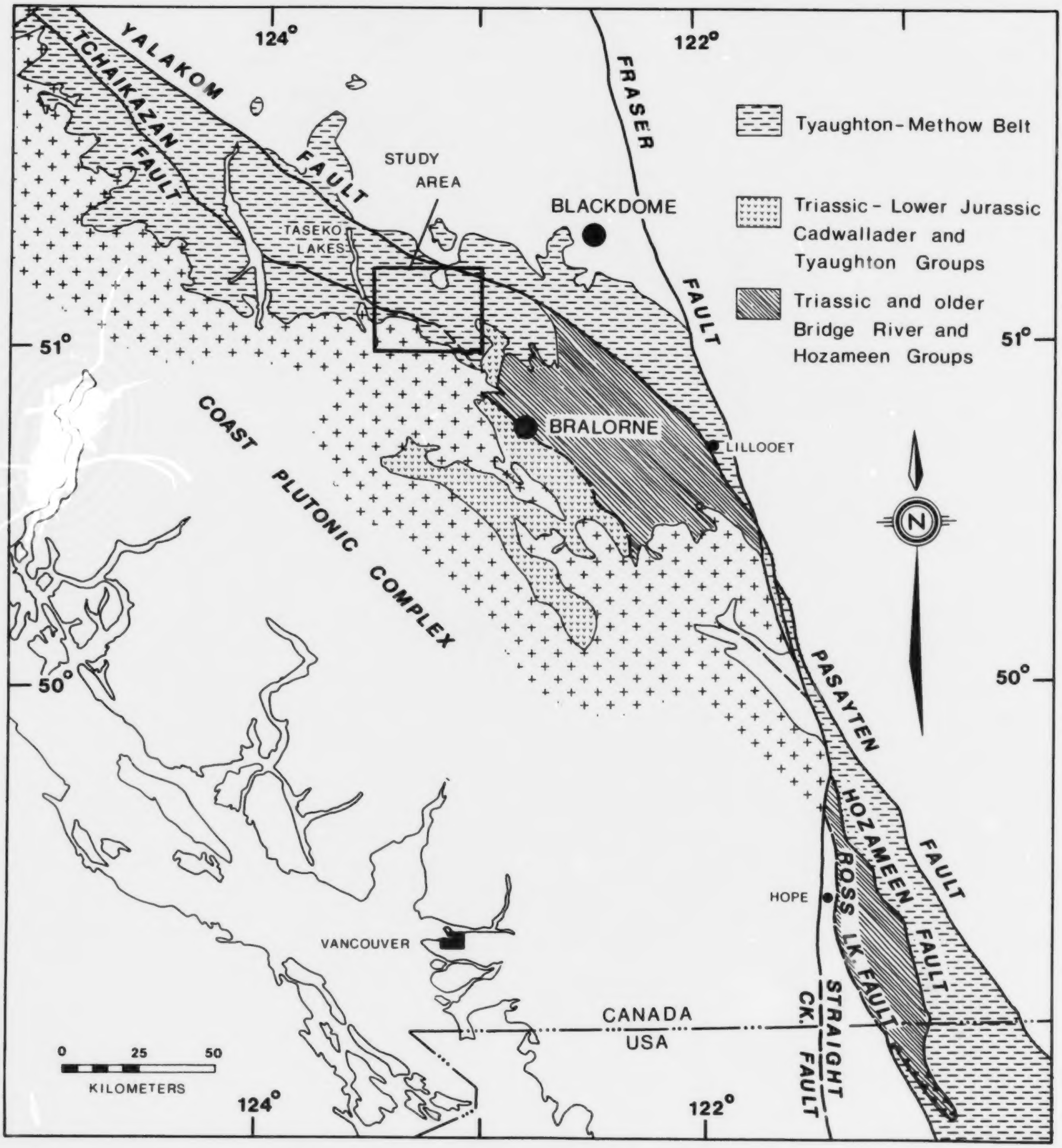

124°
122°
YALAKOM FAULT
TCHAIKAZAN FAULT
FRASER FAULT
STUDY AREA
BLACKDOME
TASEKO LAKES
Tyaughton-Methow Belt
Triassic - Lower Jurassic Cadwallader and Tyaughton Groups
Triassic and older Bridge River and Hozameen Groups
51°
COAST PLUTONIC COMPLEX
BRALORNE
LILLOOET
N
50°
PASAYTEN FAULT
HOZAMEEN FAULT
ROSS LK. FAULT
HOPE
VANCOUVER
CANADA
USA
STRAIGHT CK. FAULT
0
25
50
KILOMETERS

Figure 3-4-1. Location and geological setting, Warner Pass map sheet.

and/or chert clasts occur locally. These rocks exhibit channel crossbedding in places. This unit tends to be rusty weathering close to intrusions. Exposures in the vicinity of Lorna Lake, at the head of Big Creek, have been tentatively included within this unit. Here, greywacke, sandstone and siltstone turbidite interbeds are intercalated with minor dark grey to black shales. A collection from an apparently new fossil locality, east of Lorna Lake, may help to determine the validity of this correlation.

UNIT 3

This unit includes Upper Oxfordian (Upper Jurassic) to Barremian (Lower Cretaceous) argillaceous clastic rocks of the Relay Mountain Group (Jeletzky and Tipper, 1968). It is characterized by the abundance and excellent preservation of buchias, belemnites and, to a lesser extent, ammonites. Jeletzky and Tipper have divided the Relay Mountain Group into 16 fossil zones that demonstrate a period of continuous sedimentation throughout its deposition. This unit is well exposed east of Big Creek, but also occurs as isolated inliers west of the creek, in the central part of the area. The unit comprises a thick sequence of dark grey shale, rusty brown-weathering grey-brown siltstone, greenish grey greywacke and lithic sandstone, grit and thin conglomerate interbeds with well-rounded granitic and sedimentary clasts. Minor thin limy interbeds and concretions occur in places. Individual beds or sequences of beds are laterally discontinuous, facies changes are common and there are no obvious markers that can be traced for any distance. Hence the importance of fossil zones, as stressed by Jeletzky and Tipper (1968).

UNIT 4

This unit is equivalent to the Taylor Creek Group of Aptian to Albian (Early Cretaceous) age (Jeletzky and Tipper, 1968). The most extensively exposed areas of this unit occur east of Big Creek, but critical exposures are distributed throughout the northwestern part of the study area, where it occurs below a marked angular unconformity separating it from overlying strata of Unit 6. The unit is characterized by variable proportions of recessive dark grey to black shale, resistant, medium to thickly bedded siltstone and sandstone, and poorly bedded chert-pebble conglomerate. Sedimentary structures and invertebrate fossils indicate that these beds were deposited by turbidity currents under marine conditions. Lenses of massive conglomerate with subrounded to subangular volcanic cobbles and boulders of felsic to intermediate composition occur locally (Plate 3-4-1). Slump structures that contort bedding in the underlying argillites show that the conglomerates were deposited by mass flow processes. Felsic to intermediate volcanic and volcaniclastic rocks are intercalated with shale and siltstone of Unit 4 at two localities west of Big Creek.

UNIT 5

Unit 5 comprises sandstone, shale and conglomerate which outcrop within a tight northwest-trending syncline east of Big Creek (Figure 3-4-2). It is stratigraphically underlain by chert-pebble conglomerate and shale of Unit 4, although the contact was not observed and its nature is not currently known. Approximately 700 to 800 metres (top not exposed) of Unit 5 strata occur within the syncline. Brown-weathering grey to green sandstone is the dominant lithology. It is generally feldspathic and characteristically contains 1 to 2 per cent mica (muscovite + biotite). Wood fragments and carbonaceous patches were observed locally. Beds range from several tens of centimetres to several metres in thickness, but are not always well defined. Commonly the sandstone is intercalated with dark grey, friable shale, which dominates local portions of the section.

Granule to pebble conglomerate within Unit 5 occurs as crudely stratified layers containing laterally discontinuous intercalations of sandstone and shale. The clasts are dominantly chert and intermediate feldspar-phyric volcanic rocks, and also include granitic rocks, fine-grained clastic sediments and quartz. The sandy matrix is typically feldspathic and locally micaceous. A 5-metre-thick conformable sheet of dark brown-weathered hornblende-phyric andesite was noted within Unit 5 near the top of the exposed section; whether this represents a volcanic flow or a sill is uncertain.

Unit 5 is included within the lowermost sedimentary portion of Tipper's Kingsvale Group (1978), which also included Unit 6a of this report, and is assigned an Albian to Cenomanian age on the basis of plant fossils (Jeletzky and Tipper, 1968). It is treated separately here because its relationship to the underlying Unit 4 rocks, and to Unit 6 which rests unconformably on Unit 4 elsewhere in the area, has not yet been established. This problem will be addressed during the 1987 field season.

UNIT 6

Unit 6 comprises volcanic, volcaniclastic and clastic sedimentary rocks of latest Albian (?) (mid-Cretaceous) to late Cenomanian (Late Cretaceous) age, which were assigned to the Kingsvale Group by Jeletzky and Tipper (1968). It is the most extensively exposed stratigraphic unit within the area and occurs in three adjacent belts separated by west-northwesterly trending faults. Within the northern belt, Unit 6 rocks extend from the northwest corner of the map area, north of Chita Creek, eastward to Big Creek. Unit 6 rocks of the central belt extend the full width of the map area, from the ridges north of the lower Taseko River eastward to Mount Sheba. These rocks are bounded on the north by a normal fault, downthrown to the south, and by the Tchaikazan fault to the south.

The southern belt lies between the Tchaikazan fault and the Coast Plutonic Complex to the south. Underlying rocks are exposed in the northern belt and at the east end of the central belt; in these areas Unit 6 is seen to overlie Unit 4 and older rocks with pronounced angular unconformity (Plate 3-4-2). Unit 6 is overlain by Eocene and Miocene rocks (Units 7 and 8) in the northern and central belts and is intruded by granodiorite of the Coast Plutonic Complex in the southern belt.

Within the western part of the central belt, from the west boundary of the map sheet eastward to Denain Spur and Dorrie Peak, Unit 6 has been subdivided into three units. It comprises a sequence of clastic sediments and epiclastic rocks (Unit 6a), overlain by volcanic breccia, tuff and basaltic to andesitic flows (Unit 6b), in turn overlain by laharic breccias intercalated with bedded tuffs and epiclastic sediments (Unit 6c). This threefold subdivision seems to apply further east, in the vicinity of Lizard Lake and Mount Sheba, where a sedimentary interval, equivalent to 6a, occurs at the base of the unit. Epiclastic rocks, which may be equivalent to the lower part of Unit 6c, outcrop locally on ridge tops south of Lizard Lake, but are too thin to be shown on the accompanying sketch map; Unit 6 in this area, comprising mainly Unit 6b, is shown as undivided.

In the northern belt the basal sedimentary interval (6a) is absent in all the localities where the lower contact of Unit 6 is exposed. The bulk of Unit 6 in this area is lithologically similar to Unit 6b, although epiclastic rocks similar to those of Unit 6c occur locally. Unit 6 rocks of the southern belt, adjacent to granitic rocks of the Coast Plutonic Complex, are generally lithologically similar to Unit 6b of the central belt.

Unit 6a

Unit 6a consists of sandstone, conglomerate, shale and bedded tuff which comprise the lowest exposed element of Unit 6 along lower Powell Creek and adjacent portions of the Taseko River valley (Figure 3-4-1). An estimated 300 metres (base not seen) of incompletely exposed strata are represented by outcrops in this area. The interval is dominated by well-bedded sandstone, tuffaceous sandstone, and ash to fine lapilli tuff, in medium to dark shades of

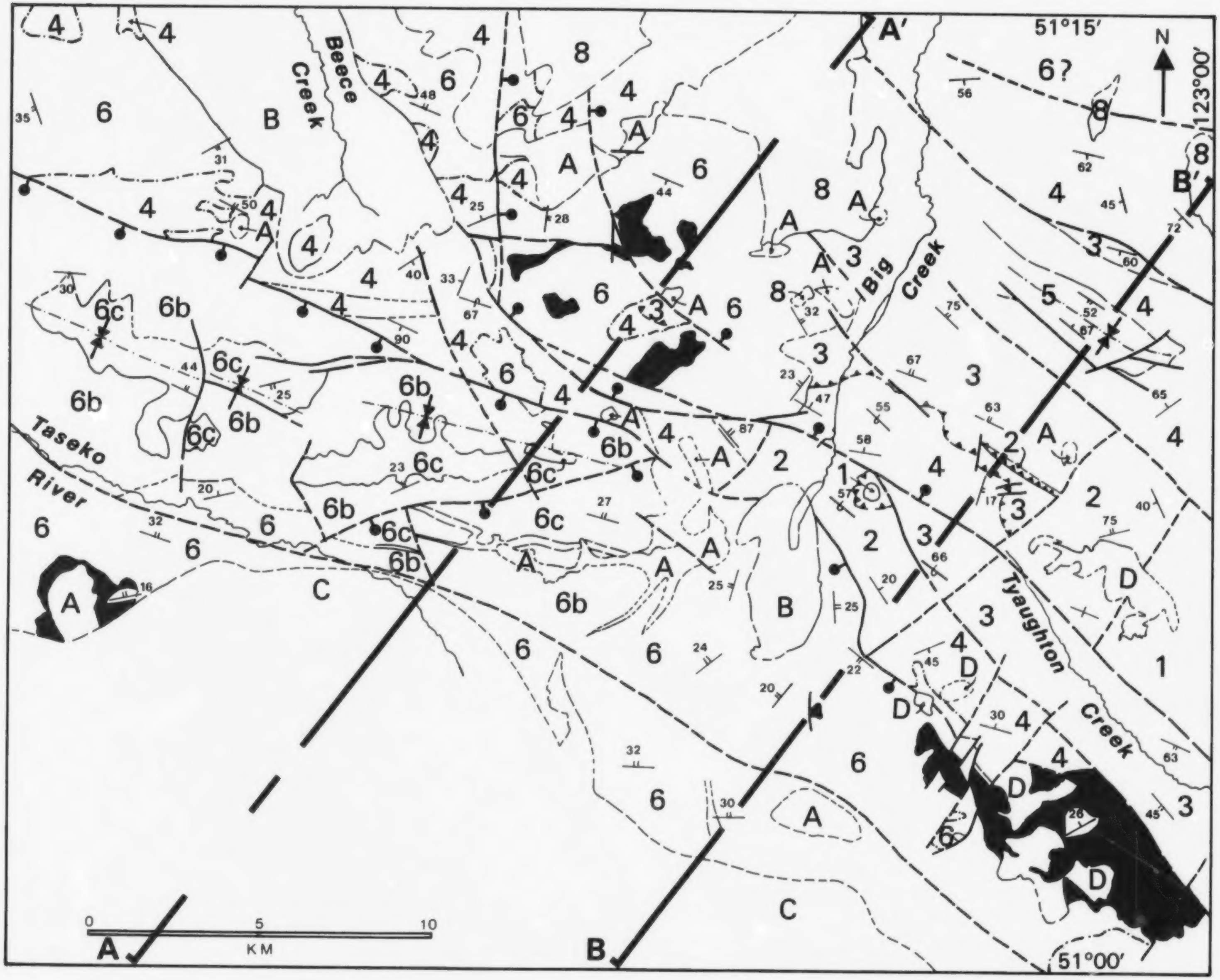
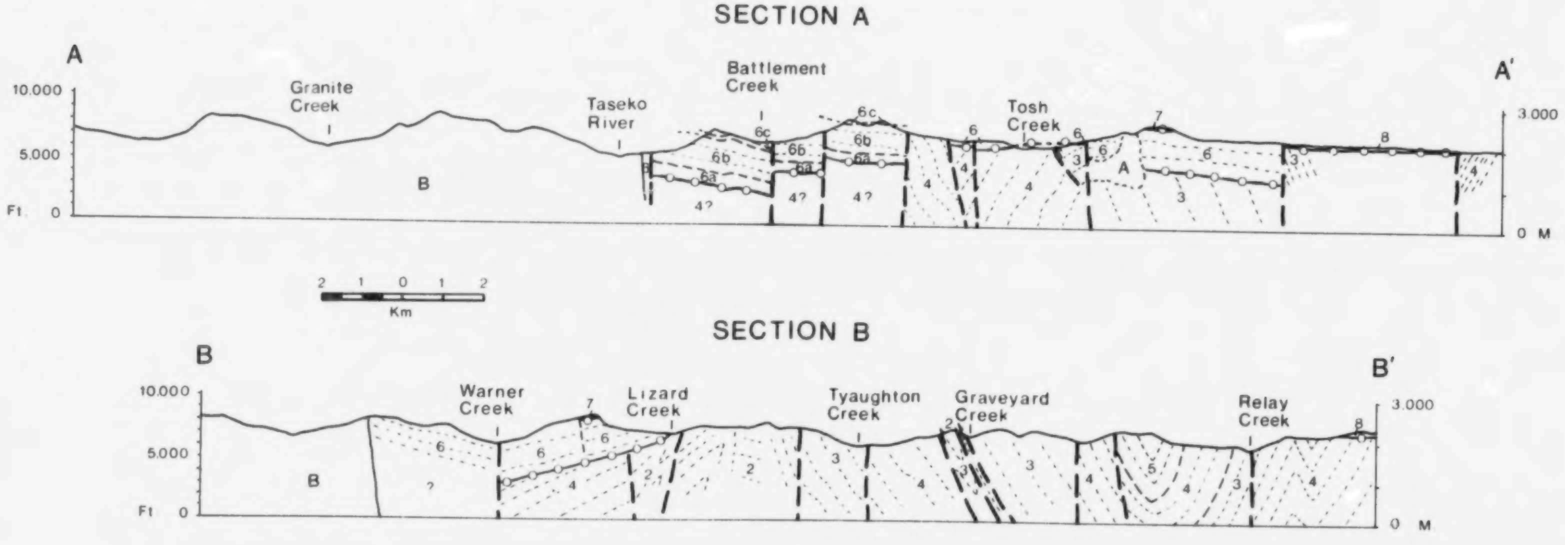

51°15′
123°00′
51°00′
N
Beece Creek
Big Creek
Tyaughton Creek
Taseko River
A
A′
B
B′
0
5
10
KM

Figure 3-4-2. Geology map and cross-sections (facing page), Warner Pass map sheet.


SECTION A
A
A′
10,000
5,000
Ft. 0
3,000
0 M
Granite Creek
Taseko River
Battlement Creek
Tosh Creek
B
6c
6b
6a
4?
4
6
3
A
7
8
2 1 0 1 2
Km
SECTION B
B
B′
10,000
5,000
Ft 0
3,000
0 M
Warner Creek
Lizard Creek
Tyaughton Creek
Graveyard Creek
Relay Creek
B
?
6
7
4
2
3
5
8

LEGEND

MIOCENE

8	*Plateau lava, basalt flows*

EOCENE (?)

■	*Rhyolite, dacite and basalt flows, pyroclastic rocks and volcanic sediments*

UPPER CRETACEOUS

6c	*Bedded laharic andesitic breccia and epiclastic sediments*
6b	*Andesitic breccia, lapilli tuff, crystal tuff and ash tuff, with minor andesitic to basaltic flows*
6a	*Volcanic sandstone and conglomerate; polymict conglomerate*
6	*Undivided; mostly Unit 6b with subordinate Unit 6a*
5	*Micaceous sandstone, shale and polymict conglomerate*

LOWER CRETACEOUS

4	TAYLOR CREEK GROUP *Argillite, siltstone, sandstone; chert pebble conglomerate and volcanic conglomerate*
4	*Dacitic to andesitic flows and volcaniclastic rocks; interbedded with shale and siltstone*

MIDDLE JURASSIC TO LOWER CRETACEOUS

3	RELAY MOUNTAIN GROUP *UPPER JURASSIC TO LOWER CRETACEOUS: Dark grey shale, grey-brown siltstone, green-grey greywacke and lithic sandstone; grit and conglomerate*
2	*MIDDLE JURASSIC: Interbedded shale, siltstone and calcarenite; greywacke, grit and conglomerate*

UPPER TRIASSIC TO LOWER JURASSIC

1	TYAUGHTON GROUP *Massive limestone; red conglomerate; grit and conglomerate interbedded with green sandstone and shale*

INTRUSIVE ROCKS

D	*Equigranular quartz monzonite to granodiorite*
C	*Hornblende plagioclase biotite porphyries with accessory quartz*
B	*Coast Plutonic Complex: quartz diorite to quartz monzonite*
A	*Hornblende plagioclase porphyries*

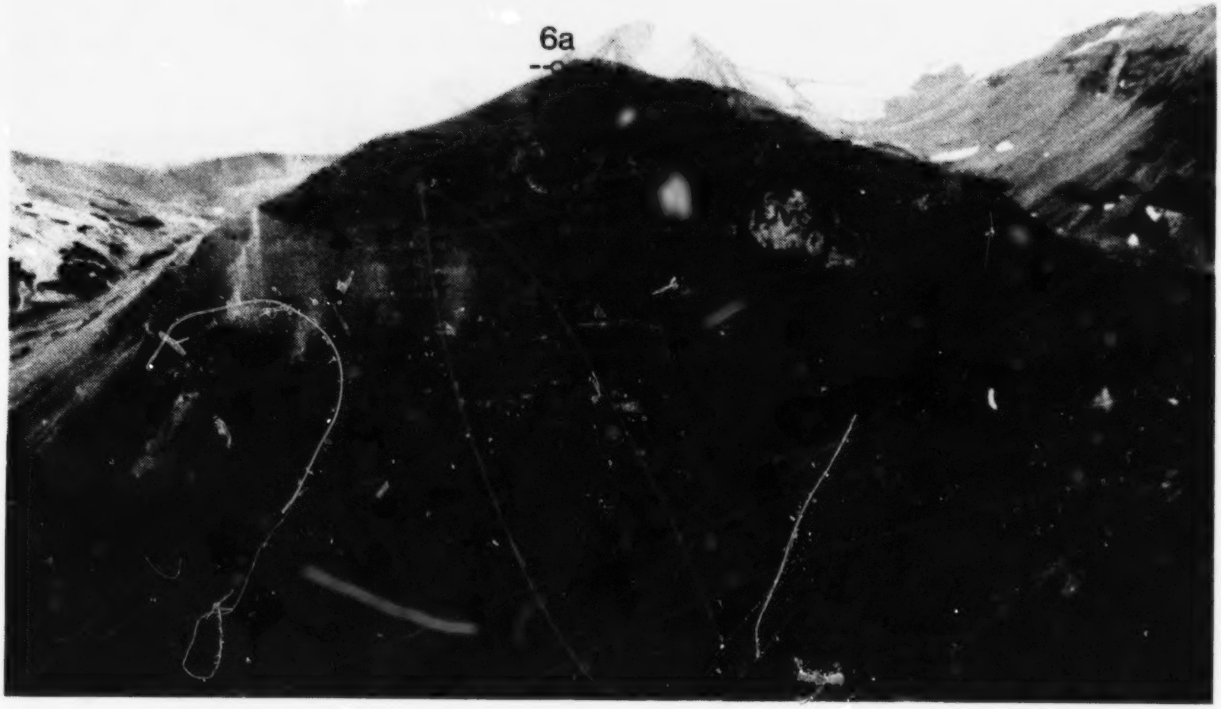


Plate 3-4-1. Slumped volcanic conglomerate interbed within argillaceous and arenaceous turbidite sequence of Unit 4; probable synsedimentary faults below the conglomeratic layer. Angular unconformity between Unit 4 and overlying polymict conglomerate of Unit 6a exposed at the top of the section, north-facing cliff section southeast of Lizard Creek.

grey, purplish grey and green. Dark grey carbonaceous shale is intercalated with the coarser clastic rocks. Pebble to boulder conglomerate occurs locally and contains mainly intermediate volcanic clasts, together with clasts of chert and fine-grained clastic sediments. Plant fragments are present in sandstone and shale and several collections have been made for paleontological analysis.

The sedimentary interval at the base of Unit 6 in the vicinity of Lizard Lake and Mount Sheba ranges up to 150 metres thick and comprises mainly conglomerate intercalated with micaceous sandstone and shale. The conglomerates vary from well-bedded pebble conglomerates to massive, poorly sorted boulder conglomerates; locally they include substantial intervals of micaceous grit containing quartz, feldspar and chert clasts. The coarse conglomerates contain mainly siltstone, sandstone (locally buchia-bearing) and intermediate volcanic clasts. Chert is usually present, but is subordinate. Locally, there is a definite progression from bedded conglomerate containing mainly sedimentary clasts at the base, upwards into massive, poorly sorted volcanic-clast conglomerate, and finally into volcanic breccia of Unit 6b. In the vicinity of Lizard Lake two ash flow tuff units, one more than 20 metres thick, occur within the upper part of the sedimentary interval.

Unit 6b

Unit 6b consists of volcanic breccia and lapilli tuff intercalated with subordinate finer-grained tuff and basaltic to andesitic flows. The unit is approximately 750 metres thick in the vicinity of Powell Creek, where both upper and lower contacts are exposed.

The breccias which characterize Unit 6b are massive, unsorted rocks comprising angular to subrounded fragments in a fine tuffaceous matrix. The clasts are mainly grey, green and purple hornblende-feldspar porphyry. The breccias vary from matrix to clast supported; clasts range up to 1 metre in size. Finer grained ash and lapilli tuffs occur sporadically within the coarser breccias and may dominate intervals several tens of metres thick. Beds of fine-grained well-bedded tuff or epiclastic sandstone, rarely more than a few metres thick, are present locally.

Volcanic flows locally comprise 20 to 30 per cent of Unit 6b, but in some sections are entirely absent. The flow rocks are mainly hornblende porphyritic andesites, similar in appearance to clasts in the volcanic breccias with which they are intercalated.

A distinctive rusty-brown-weathering, dark grey basalt, typically with feldspar and clinopyroxene phenocrysts, occurs at the top of the unit along the south side of Battlement Ridge. Similar basalt flows are common along the ridge system south of Lizard Lake, where they also underlie bedded tuffs and epiclastic sediments which may be equivalent to Unit 6c.

Unit 6c

Unit 6c consists mainly of volcanic breccia, lapilli tuff and epiclastic sediments. It lies above Unit 6b on the ridges north of the

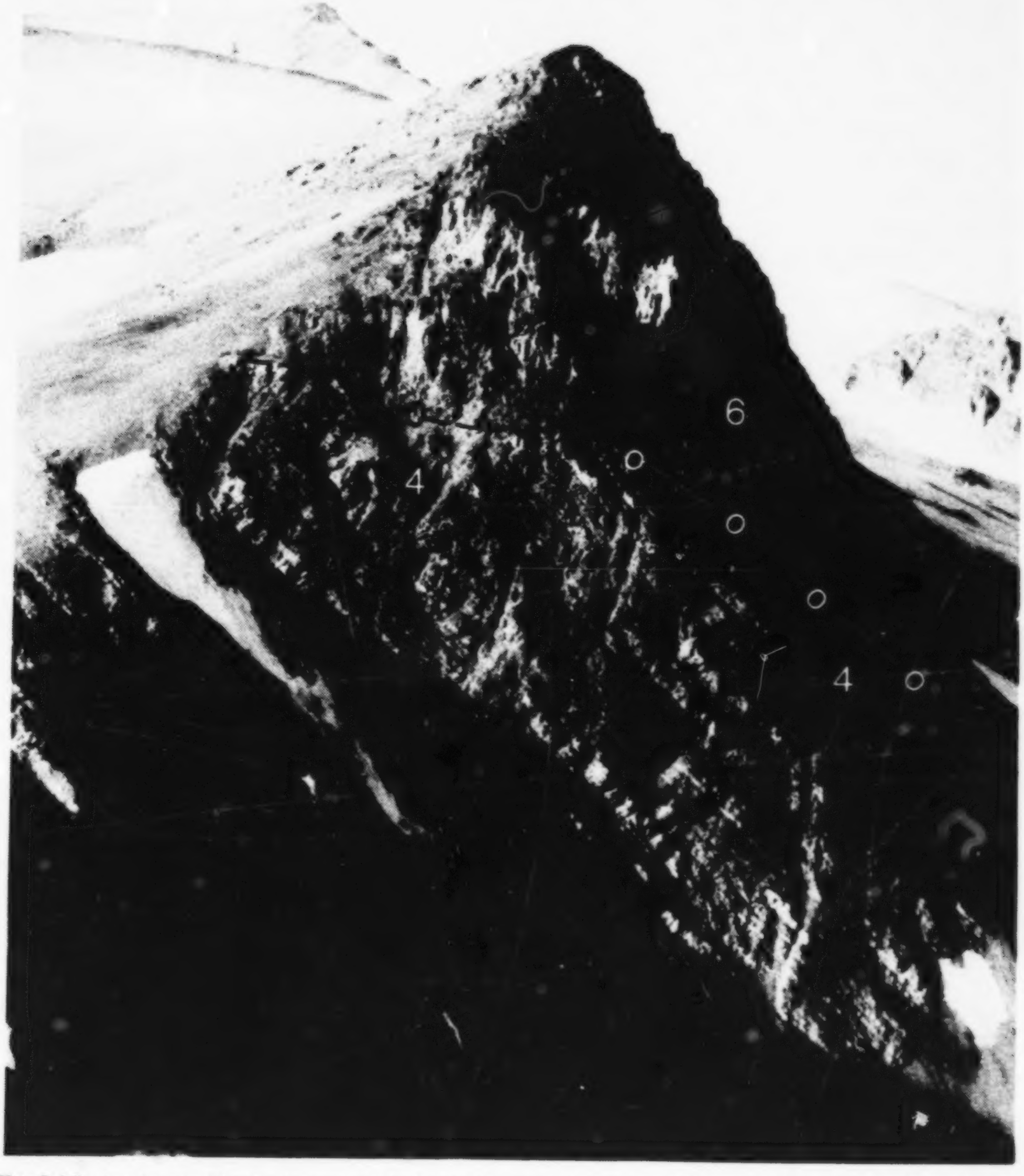


Plate 3-4-2. Angular unconformity between well-bedded turbidites of Unit 4 and overlying volcanic breccias and flows of Unit 6, 3 kilometres north of Mount Vic.

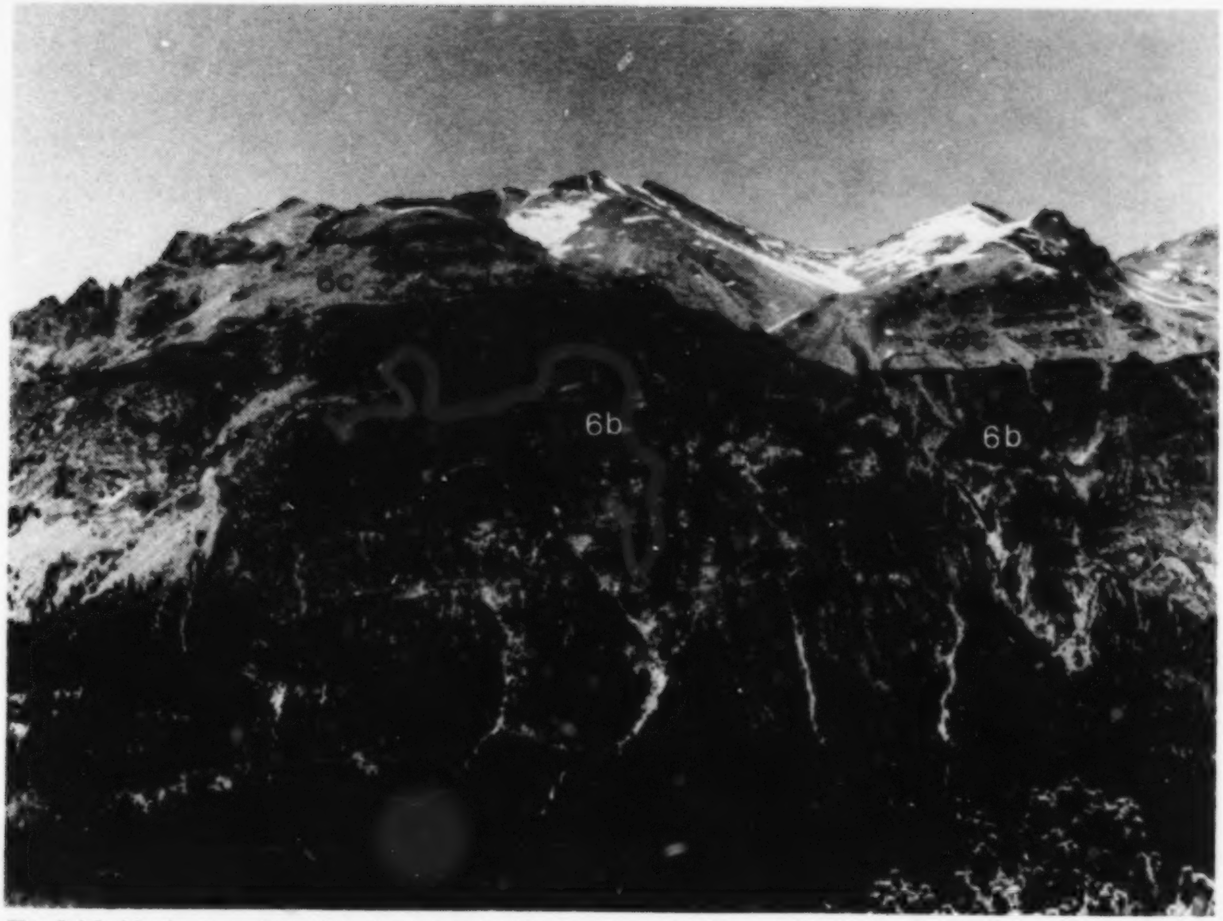


Plate 3-4-3. Massive to poorly bedded volcanic breccia with minor flows (Unit 6b) overlain by interbedded laharic breccia and epiclastic sediments (Unit 6c), south-facing cliffs of unnamed ridge north of Taseko River and Powell Creek.

Taseko River, where intercalation of recessive bedded tuffs and sediments with massive, resistant breccia give the unit a distinctive bedded aspect that contrasts markedly with the underlying massive breccias of Unit 6b (Plate 3-4-3). The top of the unit is not seen; the maximum exposed thickness is about 800 metres, on the north side of Rae Spur.

The breccias which dominate Unit 6c are in large part similar to those of Unit 6b but, particularly near the base, include intervals with a high proportion of rounded clasts. Hornblende-feldspar porphyry volcanic clasts predominate and are accompanied mainly by aphyric intermediate volcanics and rare clasts of quartz porphyry rhyolite. Intervals of purple, grey or green, well-bedded lapilli tuff occur throughout the unit and range from less than a metre to several tens of metres in thickness. Epiclastic sediments comprising volcanic sandstone and conglomerate that locally exhibit channel crossbeds and graded bedding occur mainly near the base of the unit. Plant fossils collected from a sedimentary interval south of Battlement Ridge are of Late Cretaceous age (Price, 1986). Flow rocks are rare in Unit 6c, although at least one porphyritic hornblende andesite flow occurs within it on the south side of Battlement Creek.

Unit 6 (Undivided)

Rocks assigned to Unit 6 (undivided) comprise mainly volcanic breccia similar to that of Unit 6b. On Denain Spur however it includes a thick sequence of well-stratified crystal-lithic tuffs. Epiclastic sediments and well-bedded tuffs occur locally near the top of the unit south of Lizard Lake, on Cluckata Ridge, and on the ridges west of the Dil-Dil Plateau. They may correspond to the lower part of Unit 6c. Volcanic boulder conglomerate with intercalations of epiclastic sandstone occurs within the unit on the north side of Powell Pass. Basaltic and andesitic flows are of only local importance, but dominate the unit directly west of the Dil-Dil Plateau. Flows, including rusty-brown-weathering porphyritic clinopyroxene basalt similar to that at the top of Unit 6b on Battlement Ridge, are also common to the southwest of Taseko Mountain.

UNIT 7

Unit 7 comprises volcanic and sedimentary rocks of probable Eocene age that unconformably overlie Unit 6 and older rocks (Plate 3-4-4). The unit occurs in two separate areas; it outcrops for approximately 10 kilometres along a northwest-trending ridge system centred at Mount Sheba and in the north-central part of the map area, where it occurs as several outliers on Cluckata Ridge and Dil-Dil Plateau.

In the Mount Sheba area, Unit 7 comprises dacitic rocks overlain by basalt and basaltic breccia, and is extensively intruded by porphyries of Unit C that are probably subvolcanic in character (*see* following). The lower part of the unit is characterized by purple to grey, locally flow-banded dacite with small feldspar and hornblende

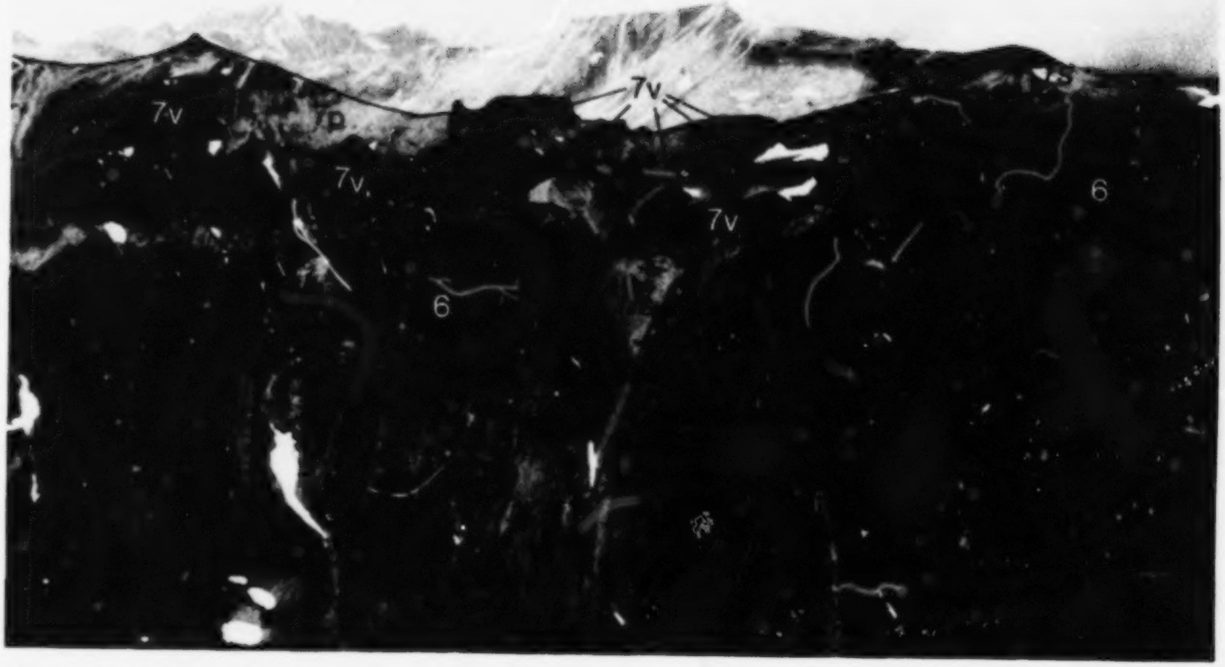


Plate 3-4-4. Angular unconformity at the base of Unit 7; laterally discontinuous horizons of epiclastic sediments (7s), volcanic flows (7v) and pyroclastic rocks (7p) exposed above the unconformity, southern slopes of Cluckata Ridge.

phenocrysts in places, intercalated with dacitic breccias of both autoclastic and pyroclastic origin, quartz-eye rhyolite flows that are locally glassy, and lenses of pebble conglomerate and sandstone. Directly south and west of Mount Sheba this dacitic section is missing and is replaced by a poorly sorted boulder conglomerate, mainly comprising well-rounded granite and hornblende-feldspar porphyry clasts in a sandy matrix of quartz, biotite and feldspar. The upper part of the unit comprises basaltic flows, typically several metres thick, with associated flow breccias. These rocks contain clinopyroxene phenocrysts in places and are sparsely vesicular and/or contain quartz amygdules. Coarse epiclastic (?) rocks with well-rounded clasts of basalt, up to 20 centimetres in diameter, are locally intercalated with the flows.

In the north-central part of the map sheet an irregular, but generally flat-lying, angular unconformity separates volcanics and volcanic breccias of Unit 6 from the overlying volcanic and volcaniclastic rocks assigned to Unit 7. Here, this unit comprises dark brown-weathering, medium grey columnar-jointed feldspar and quartz-feldspar porphyritic flows intercalated with light grey porphyritic flows containing quartz and minor feldspar phenocrysts; pink to grey, quartz-bearing crystal tuffs; and pyroclastic (?) breccias containing aphyric to feldspar-phyric volcanic fragments and rare clasts of flow-banded quartz porphyry rhyolite. The base of the unit is commonly marked by an interval of light grey to greenish grey, channel-bedded medium to coarse-grained epiclastic sediments, locally associated with thinly parallel-bedded to laminated ash tuffs and tuffaceous shales. Sandstone and shale interbeds are rare elsewhere in the unit. Plant fragments occur locally within the sedimentary rocks and were sampled for paleontological analysis.

An interval of felsic rocks which outcrops near the west boundary of the map area, south of the Taseko River, is tentatively included in Unit 7, but lithologic features are largely obscured by alteration. However, rocks within this area do include feldspar and quartz-bearing tuffs and flow-banded rhyolite similar to lithologies observed elsewhere in Unit 7.

UNIT 8

Miocene plateau basalts of Unit 8 unconformably overlie older rocks in the north-central and northeastern parts of the study area. They outcrop extensively on the Dil-Dil Plateau immediately west of Big Creek, where the maximum exposed thickness is about 150 metres. The basal flows locally lap onto paleo-hills comprising older porphyritic intrusions. However, in general the pre-Miocene erosional surface appears to have been gently undulating with perhaps a very shallow (up to 5 degrees) dip toward the northeast. The most southwesterly exposures of Unit 8 occur as an isolated outlier above the 2600-metre elevation at the head of Tosh Creek, 5.5 kilometres southwest of the Dil-Dil Plateau. Flows are columnar jointed and typically 2 to 3 metres thick, comprising markedly vesicular fine-grained basalt with well-preserved pahoehoe texture in places.

INTRUSIVE ROCKS

UNIT A — HORNBLENDE PLAGIOCLASE PORPHYRIES

The four largest stocks of this composition that occur within the study area are: the Dorrie Peak stock, 3 kilometres west of Big Creek; the Vic Lake stock in the northern part of the area; the Warner Lake stock in the southeastern part of the area; and the stock north of Mount McClure, 3 kilometres south of the Taseko River. All four stocks comprise aphanitic rocks with variable proportions of plagioclase and hornblende phenocrysts. Porphyry locally grades into equigranular medium-grained diorite in the Dorrie Peak stock. All have undergone varying degrees of chlorite-epidote alteration. Some smaller hornblende plagioclase porphyry stocks appear to be more felsic in composition and locally have iron carbonate alteration associated with them. These two possibly distinct suites may be respectively, late Cretaceous and Eocene in age.

UNIT B — QUARTZ DIORITE TO QUARTZ MONZONITE OF THE COAST PLUTONIC COMPLEX

Rocks of Unit B, comprising the northeastern margin of the Coast Plutonic Complex, cover an extensive area in the southwestern part of the map area where they intrude Unit 6. They comprise coarse to medium-grained, generally equigranular quartz diorite to quartz monzonite, with partially chloritized subhedral biotite and hornblende in variable proportions. They are commonly crosscut by hornblende feldspar porphyry dykes that appear to form the locus of alteration zones, particularly along the margin of Unit B.

Middle to Late Cretaceous dates (84.7 to 86.7±2.5 million years) have been obtained by potassium-argon radiometric dating on biotite separates from granodiorite and from a crosscutting dyke, located at the Mohawk showing, near Granite Creek south of the Taseko River (McMillan, 1976). Another potassium-argon date published by McMillan, on sericite from an alteration zone at this locality, falls within the same age range. These are the only radiometric dates so far published from rocks of the Warner Pass map sheet. However, Unit B rocks are included within a regionally extensive belt of Early Tertiary intrusive rocks on the 1:1 000 000 Fraser River map sheet (Roddick *et al.*, 1979). A radiometric dating program will be initiated during the 1987 field season in order to address this and other problems.

UNIT C — HORNBLENDE PLAGIOCLASE BIOTITE PORPHYRIES WITH ACCESSORY QUARTZ

These rocks occur as two groups of small stocks of irregular shape in the Mount Sheba area and on the ridge northeast of Tyaughton Creek. They contain hornblende, plagioclase and biotite phenocrysts in variable proportions in an aphanitic leucocratic matrix. Stocks in the Mount Sheba group typically contain quartz phenocrysts. Rhyolitic and dacitic flows and pyroclastics of Unit 7, particularly voluminous in the Mount Sheba area, are intruded by and locally are in fault contact with both groups. The stocks are therefore interpreted as volcanic centres of probable Eocene age.

UNIT D — EQUIGRANULAR QUARTZ MONZONITE TO GRANODIORITE

These plutonic rocks occur in two intrusive bodies: the Beece Creek pluton in the northwest part of the area and the Lorna Lake stock at the head of Big Creek. They comprise fine to medium-grained equigranular quartz monzonite to granodiorite with partly chloritized biotite and/or hornblende.

A prominent roof pendant of Unit 4 in the southwestern part of the Beece Creek pluton demonstrates that, at least here, the present erosion level is close to the top of the intrusion. The southwestern and northeastern contacts of this stock are vertical to steeply dipping with a relatively uniform northwest strike and may have been controlled by pre-intrusive high-angle faults.

Both intrusions locally crosscut the hornblende plagioclase porphyries of Unit A and may be Tertiary in age.

DYKES

A wide variety of narrow, north to northwest-trending dykes occurs throughout the map area. The most common are quartz-feldspar and quartz porphyries, hornblende-feldspar porphyry and aphyric felsite. Felsic varieties commonly have clay alteration, sericitization, and/or iron-carbonate alteration along them, whereas hornblende-feldspar porphyry dykes typically show chlorite-epidote alteration. Diabase and basalt dykes are the least common and are usually unaltered.

STRUCTURE

OVERVIEW

The overall structural pattern in the area is dominated by northwest-trending high-angle normal and reverse faults.

A pronounced angular unconformity, well exposed at several localities in the northwest quadrant of the map sheet, separates Upper Cretaceous (Cenomanian?) nonmarine strata of Unit 6 from underlying latest Lower Cretaceous (Albian) marine strata of Unit 4. Above the unconformity Unit 6 rocks are typically gently dipping and locally warped into broad westerly trending folds. In contrast, below the unconformity Unit 4 and older rocks display steep, locally overturned, generally northwest-trending bedding attitudes as a result of folding and thrust faulting prior to deposition of Unit 6.

PRE-UNIT 6 STRUCTURES

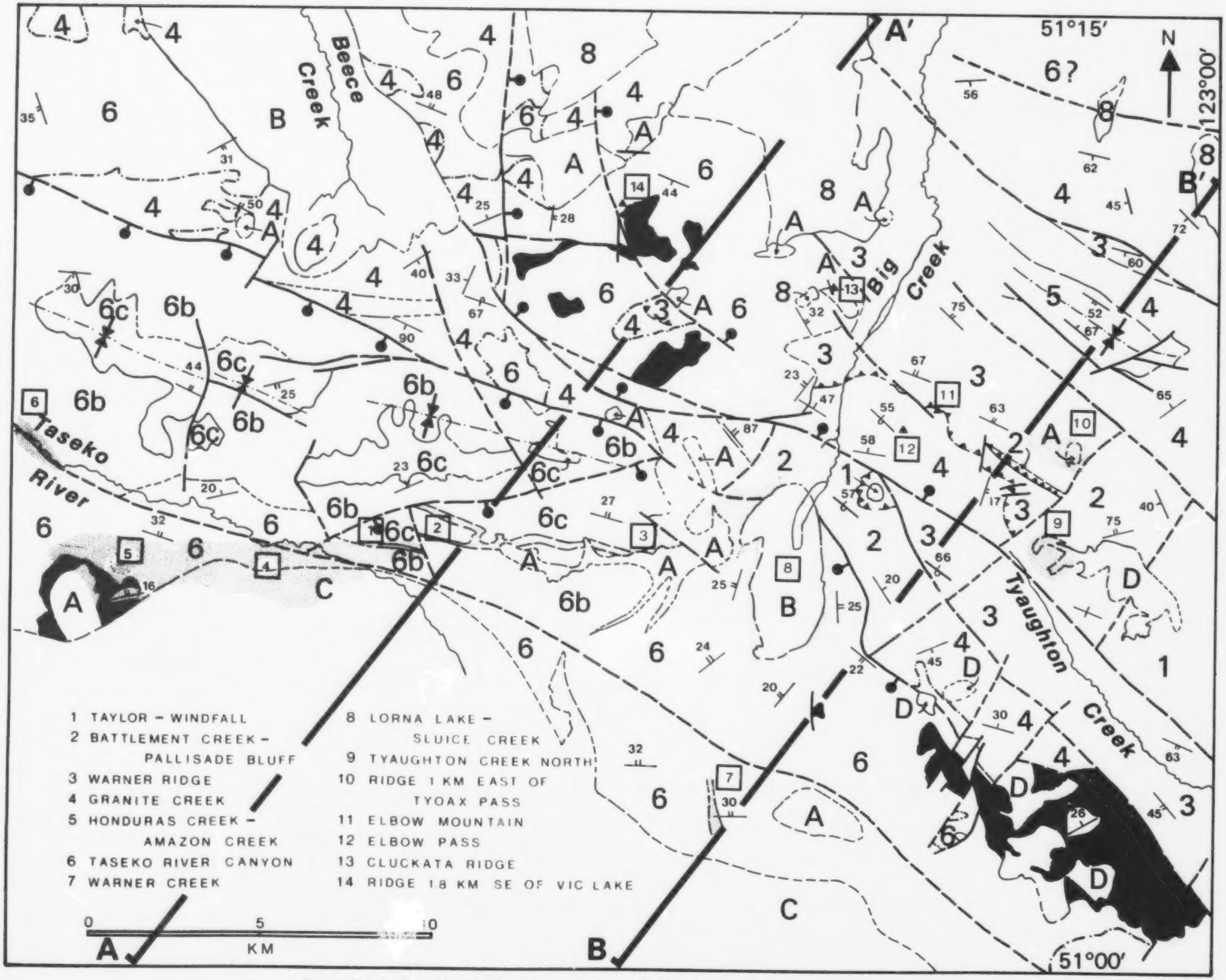
Thrust faults, that typically occur along bedding glide zones with minor cataclasis, are demonstrated by reversal and repetition of fossil zones in the older rocks east of Big Creek (Jeletzky and Tipper, 1968). Thrust faulting of these older rocks is also established by the juxtaposition of Unit 1 above Unit 2 east of Lorna Lake. Moreover, small-scale southerly directed thrusts have been observed within Units 1, 2 and 4, east of Big Creek.

Thrust faults and related folds are not observed in Unit 6. An inferred thrust that places Unit 3 on Unit 4 has been traced for 5 kilometres east of Big Creek; west of Big Creek it is truncated by the unconformity at the base of Unit 6. Five kilometres to the northwest it re-emerges from beneath the unconformity within an inlier along Tosh Creek (*see* Section A, Figure 3-4-2). Here it separates fossiliferous Unit 3 rocks on the northeast from argillites and coarse clastic rocks assigned to Unit 4 on the southwest.

Pre-unit 6 structures also include a northeast-trending, steeply dipping fault along Lizard Creek which juxtaposes Unit 2 on the northwest against Unit 4 on the southeast (*see* Section B, Figure 3-4-2). It is truncated by a northwest-trending normal fault of limited displacement and does not occur in Unit 6 rocks to the southwest. The probable northeast extension of the Lizard Creek fault juxtaposes Unit 3 against Unit 2 northeast of Tyaughton Creek.

SYN (?) AND POST-UNIT 6 STRUCTURES

Generally northwest-trending, locally sinuous normal faults offset Unit 6 and/or Unit 7 and many of the intrusive rocks. East of the Beece Creek pluton and west of Big Creek the sense of movement on these faults is down to the east, whereas to the southwest of the pluton their sense of movement is down to the southwest.



51°15′
123°00′
51°00′
N
A
A′
B
B′
Beece Creek
Big Creek
Taseko River
Tyaughton Creek
1 TAYLOR – WINDFALL
2 BATTLEMENT CREEK – PALLISADE BLUFF
3 WARNER RIDGE
4 GRANITE CREEK
5 HONDURAS CREEK – AMAZON CREEK
6 TASEKO RIVER CANYON
7 WARNER CREEK
8 LORNA LAKE – SLUICE CREEK
9 TYAUGHTON CREEK NORTH
10 RIDGE 1 KM EAST OF TYOAX PASS
11 ELBOW MOUNTAIN
12 ELBOW PASS
13 CLUCKATA RIDGE
14 RIDGE 1.8 KM SE OF VIC LAKE
0
5
10
KM

Figure 3-4-3. Location of mineral occurrences and alteration zones, Warner Pass map sheet.

One of these faults, the Chita Creek fault (Figure 3-4-2), can be traced from the western boundary of the map area as far as the head of Big Creek, where it is truncated by the Lorna Lake stock. It has at least 600 metres of vertical displacement in the vicinity of Powell Creek, south of the Beece Creek pluton, where it juxtaposes the base of Unit 6 on the north against the lower part of Unit 6c on the south. It can be traced to the southeast of the Lorna Lake stock, but here there is evidence of considerably less displacement. It is poorly defined further to the southeast, but may have controlled the distribution of Eocene (?) volcanic and intrusive rocks at Mount Sheba.

In the western half of the map sheet the Chita Creek fault is the locus of marked lithostratigraphic differences within the lower part of Unit 6; northeast of the fault volcanic flows and breccias lie directly above the unconformity at the base of Unit 6, whereas to the southwest the lower part of the unit comprises at least 300 metres of locally coarse clastic and epiclastic sedimentary rocks (Unit 6a). The coarser conglomeratic intervals within Unit 6a may represent periods of reactivation along the fault, which is thought to define the northeast margin of a local half (?)-graben within which Unit 6a was deposited.

The northwest-trending Tchaikazan fault has been traced across the Taseko Lakes map area by Tipper (1978). It continues to the northwest into the Mount Waddington map area, where 30 kilometres of right-lateral offset has been postulated (Tipper, 1969). Within the study area, its trace, as defined by Tipper, follows the Taseko River valley, through Warner Pass and along Gun Creek toward the southeast. In the Taseko River canyon, a northwest-trending zone of intense brecciation has been the locus of narrow zones of alteration parallel to the trace of the fault. To the southeast, at the confluence of Powell Creek with the Taseko River, the fault juxtaposes Unit 6a, at the base of Unit 6, on the north, against undifferentiated Unit 6 on the south. Further to the southeast, the fault may be traced along a pronounced lineament, but no stratigraphic offset can be demonstrated across it.

Numerous northerly trending high-angle faults of the same generation or younger occur throughout the area. Most have small displacements, although east of Big Creek they appear to be mostly dextral in nature.

STRUCTURES OF UNCERTAIN AGE

East of Big Creek, northwest-trending faults are dated only as post-Albian in age. Some of them may have strike-slip movement along them (P. Umhoefer and J. Garver, personal communication, 1986) and may be related to the Yalakom fault. The extension of these structures to the northwest is uncertain due to the presence of Miocene cover.

In the northeastern part of the map sheet a tight upright syncline involves strata of Unit 4 and Unit 5. The age of this structure relative to the pre-unit 6 unconformity is unknown.

MINERALIZATION AND ALTERATION

Figure 3-4-3 shows the location of the significant alteration zones in the area. Some of them are known to contain gold mineralization and/or anomalously high geochemical values in gold and related elements. Most display striking hydrothermal alteration characteristics and vary from those typically associated with porphyry copper-molybdenum deposits to those more characteristic of epithermal precious metal deposits.

Taylor-Windfall (Location 1, Figure 3-4-3) is the only occurrence with recorded gold production. Limited production during the mid-1930s came from both surface and underground workings on a narrow, northeast-striking fracture zone containing pyrite, tennantite, chalcopyrite and minor sphalerite in a chlorite-sericite gangue (*Minister of Mines, B.C.*, 1935). In the period 1952 to 1953, further underground mining resulted in the recovery of 886.5 grams of gold extracted from 63.5 tonnes of ore with an average mining grade of 20.6 grams per tonne. Production came from a narrow flat-lying pyroclastic bed within Unit 6 (Lane, 1983). Since 1983 renewed exploration of the Taylor-Windfall property and the surrounding area, conducted by Westmin Resources Ltd. and Esso Minerals Canada, has focused upon siliceous zones with associated argillic and phyllic alteration. A limited amount of diamond drilling has been undertaken in conjunction with detailed geological mapping and geochemical sampling. No reserves have been published to date.

The siliceous zones at Taylor-Windfall and to the northeast, along Palisade Bluff and east of Battlement Creek (Location 2, Figure 3-4-3), appear to be stratabound and hosted by pyroclastic and epiclastic rocks at the base of Unit 6c. A chlorite-epidote-altered plagioclase porphyry flow (?) which immediately overlies the siliceous zone on Palisade Bluff, may have acted as an impermeable barrier to the mineralizing fluids. Alunite, dickite and finely disseminated pyrite occur locally within these alteration zones. Small cavities filled with drusy quartz, rutile, tourmaline and pyrite have also been observed (Lane, 1983). In addition, tourmaline and andalusite have been reported from the alteration zone at Taylor-Windfall (Price, 1986). The geometry and mineral assemblage of these alteration zones indicate a transition from an epithermal setting to a deeper porphyry system.

The siliceous zone at Palisade Bluff can be traced along the same stratigraphic horizon to a spur immediately north of Warner Ridge (Location 3, Figure 3-4-3) where a zone of variably developed clay alteration and silicification at least 10 metres thick is exposed over a strike length of approximately 300 metres and has a dip extent to the southeast of about 300 metres. A single rock sample from this zone returned anomalous geochemical values in gold (300 parts per billion) and mercury (500 parts per million). Other samples from the zone have no detectable gold values, but some are anomalously high in mercury and arsenic.

Gold values have been reported from a group of showings that occur within a hydrothermal alteration zone along the margin of the Coast Plutonic Complex (Location 4, Figure 3-4-3). This zone was explored for porphyry copper-molybdenum deposits during the period 1950 to 1976. Gold and minor silver values are associated with chalcopyrite and molybdenite mineralization that occurs as disseminations and veins or in intrusive breccia in granitic rocks of Unit B (McMillan, 1976). Gold is also associated with pyrite and chalcopyrite mineralization in the volcanic rocks of Unit 6.

The western extension of this zone, between Honduras and Amazon Creeks (Location 5, Figure 3-4-3), comprises pervasive disseminated pyrite mineralization and associated quartz-tourmaline veins within a zone of advanced argillic alteration and silicification of volcanics and volcanic breccias assigned to Unit 6 (Bradford, 1985). The southwestern part of the zone includes siliceous rocks that surround a chlorite-epidote-altered hornblende-plagioclase porphyry. This may represent a subvolcanic intrusive complex; its relationship to the Coast Plutonic Complex is unclear.

A group of bright yellow to orange-weathering *en echelon* hydrothermal alteration zones are exposed along the trace of the Tchaikazan fault in the Taseko River canyon at the western margin of the map area (Location 6, Figure 3-4-3). They strike approximately 320 degrees and dip vertically. The largest zone is 1 kilometre long and up to 100 metres wide. They all comprise silicified and sericitized volcanic rocks of Unit 6, are cut by northwest-trending carbonate veins, and locally contain up to 10 per cent disseminated fine-grained pyrite. Samples from this area have high geochemical values in mercury and arsenic and one sample, from immediately west of the map sheet boundary on the north side of the canyon, was anomalous with respect to gold.

Alteration in the area of Warner Creek (Location 7, Figure 3-4-2) bears a striking resemblance to that observed in the Taylor-Windfall area. A prominent, steeply dipping, north-trending zone of intense silicification, that locally contains up to 10 per cent finely disseminated pyrite, crosscuts and partly replaces volcanic rocks of Unit 6 that dip gently to the north. The exposed strike length of the zone is 1.7 kilometres and its maximum width is about 300 metres. Narrow quartz tetrahedrite veins, reportedly anomalous in gold (Gruenwald, 1980), occur at its northern end along Warner Creek. Clay alteration was observed locally along the ridge at its south end. Nearby a 4-metre-wide zone (bed?) of silicified lapilli tuff, that conforms with the orientation of bedding measured elsewhere, merges with the eastern margin of the main siliceous zone. This alteration zone is located 1.5 kilometres west of a relatively large hornblende plagioclase porphyry stock that is pervasively chlorite-epidote altered and contains locally abundant malachite, both along fracture surfaces and as disseminations.

Mineral occurrences elsewhere on the map sheet appear to be associated with intrusive rocks of probable Eocene age, both as stocks (Locations 8, 9, 10, 13 and 14, Figure 3-4-3) and as narrow felsic dykes (Locations 11 and 12, Figure 3-4-3).

MINERAL POTENTIAL

Known gold mineralization and/or geochemical anomalies, associated with pronounced hydrothermal alteration zones in volcanic, sedimentary and intrusive rocks, demonstrate the potential for epithermal and mesothermal precious metal deposits. Only a few of the occurrences shown in Figure 3-4-3 have been adequately tested and the area presents an opportunity for future exploration.

Compilation of analyses of lithogeochemical samples taken during the course of this study will be included as part of the final mineral potential map.

TECTONIC IMPLICATIONS

This study documents critical field relationships that provide constraints on the geometry and timing of deformation along the eastern margin of the Coast Plutonic Complex. Upper Triassic to Lower Cretaceous marine sedimentary and volcanic strata of the Tyaughton trough contain southerly directed thrusts and tight, locally overturned folds. These rocks and associated structures are separated from the overlying Upper Cretaceous nonmarine volcanic and sedimentary strata by a profound angular unconformity. The mid-Cretaceous deformation event demonstrated by these stratigraphic and structural relationships correlates well with the timing of the accretion of the Insular superterrane to western North America, proposed by Price *et al.* (1985). However, the Cenomanian age attributed to volcanic and sedimentary rocks of Unit 6, above the unconformity, is based on plant fossils (Jeletzky and Tipper, 1968) and is poorly constrained. It is hoped that more precise dates can be obtained, particularly for the base of Unit 6, by palynological analysis or by radiometric age determinations. The spatial and temporal relationships of structures confined to the older rocks below the unconformity, with respect to transcurrent movement along the Yalakom fault, are unknown at this time. These problems will be addressed during the 1987 mapping program.

ACKNOWLEDGMENTS

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GEOLOGY OF WHITESAIL REACH AND TROITSA LAKE MAP AREAS*
(93E/10W, 11E)

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INTRODUCTION

This report describes the geology and several types of mineral occurrences, indicative of an epithermal setting, found in the Whitesail Reach (93E/10W) and Troitsa Lake (93E/11E) map areas. About 650 square kilometres was mapped at 1:25 000 scale and the geology compiled on 1:50 000 map sheets. The geological map, accompanied by a mineral occurrence and alteration location map of the area covered during 1986, will be published as an Open File series in January 1987. This regional mapping constitutes the initial phase of a four-year program jointly funded under the Canada/British Columbia Mineral Development Agreement. The main objective of regional mapping in the Whitesail Lake area is to evaluate Upper Cretaceous and Tertiary volcanic and coeval plutonic rocks as a probable host for epithermal and mesothermal gold-silver-copper-lead-zinc mineralization.

LOCATION AND ACCESS

The study area is accessible from Burns Lake by 60 kilometres of pavement to Ootsa Landing and then by an all-weather gravel road to the Alcan boat launch at Andrew Bay, 31 kilometres to the west (Figure 3-5-1). Shallow draught boats are an economical and effective mode of access to areas of subdued topography adjacent to Tahtsa Reach, Whitesail Reach and Whitesail Lake. The mountainous terrain of the Whitesail Range is accessible by helicopter from bases at either Smithers or Houston, 130 kilometres and 90 kilometres to the north respectively.

Outcrop is extensive in the Whitesail Range, where alpine conditions prevail. At elevations below 1450 metres Quaternary gravel, forest and swamp obscure most rock exposure. The best outcrops below treeline are along the shorelines of Tahtsa Reach and Whitesail Lake and in stream valleys.

TECTONIC SETTING

The Whitesail Lake map area is near the boundary of the Coast Crystalline and Intermontane Belts (Figure 3-5-2). At this latitude the Coast Crystalline Belt is mainly comprised of metamorphosed and deformed rocks of probable Paleozoic age that are gradational into, or intruded by Cretaceous and Tertiary plutonic rocks (Woodsworth, 1979). Immediately to the east, the Intermontane Belt is underlain by mildly deformed Lower Jurassic to Tertiary volcanic and sedimentary rocks disrupted by block faults.

LOCAL GEOLOGY

The oldest rocks within the study area are the Telkwa Formation, Smithers Formation and Ashman Formation of Early to Middle Jurassic age. These rocks are overlain with angular discordance by the Ootsa Lake Group, which is thought to be Upper Cretaceous to Lower Tertiary. The distribution of rocks mapped in the study area is shown in Figure 3-5-3 and their relative stratigraphic positions summarized in Figure 3-5-4.

Faults delimit downdropped blocks that locally preserve thick sections of Ootsa Lake Group strata. Elsewhere within the area these rocks have been eroded, exposing variably deformed Lower Jurassic rocks.

In several areas quartz veins and zones of pervasive hydrothermal alteration, spatially associated with high-level intrusions, contain anomalous concentrations of gold, mercury and arsenic.

LOWER TO MIDDLE JURASSIC ROCKS

Jurassic rocks conform with the stratigraphic divisions proposed by Tipper and Richards (1976) for north-central British Columbia. Heterogeneous pyroclastic rocks and flows of the Telkwa Formation form the basement in the area. These rocks are overlain by the Smithers Formation, which consists mainly of arkosic sediments, locally gradational into an upper, dominantly pyroclastic section. The youngest rocks of Jurassic age are interbedded sandstone, siltstone and shale assigned to the Ashman Formation.

TELKWA FORMATION (UNIT 1)

The Telkwa Formation has widespread distribution southeast of the Whitesail Range to the shore of Whitesail Lake. It consists mainly of andesitic lapilli tuff and tuff breccia irregularly interlayered with flows ranging in composition from basalt to rhyolite. These rocks typically are green to maroon and have ubiquitous chlorite, epidote, calcite and laumontite developed in the matrix and in fractures. Plagioclase phenocrysts, ranging from 2 to 5 millimetres long, and chloritized mafic minerals are diagnostic features of the porphyritic rocks.

Rhyolite occurs as homogeneous flows, locally more than 200 metres thick. They are salmon pink, cream and less commonly green or grey in colour. Flow layering and spherulites are common textures.

SMITHERS FORMATION (UNIT 2)

The lower, dominantly marine sedimentary facies of the Smithers Formation forms scattered outcrops in the low forested terrain adjacent to Tahtsa Reach. This sequence is more than 880 metres thick in the western Whitesail Range. It consists of alternating grey-green beds of coarse arkosic sandstone, siltstone and granule-pebble conglomerate. Chert, shale, limestone and concretionary siltstone interbeds are also present, but are not widespread. Individual beds generally range from 10 centimetres to more than 1 metre thick. Planar and graded bedding is common, but cross-stratification is rare.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

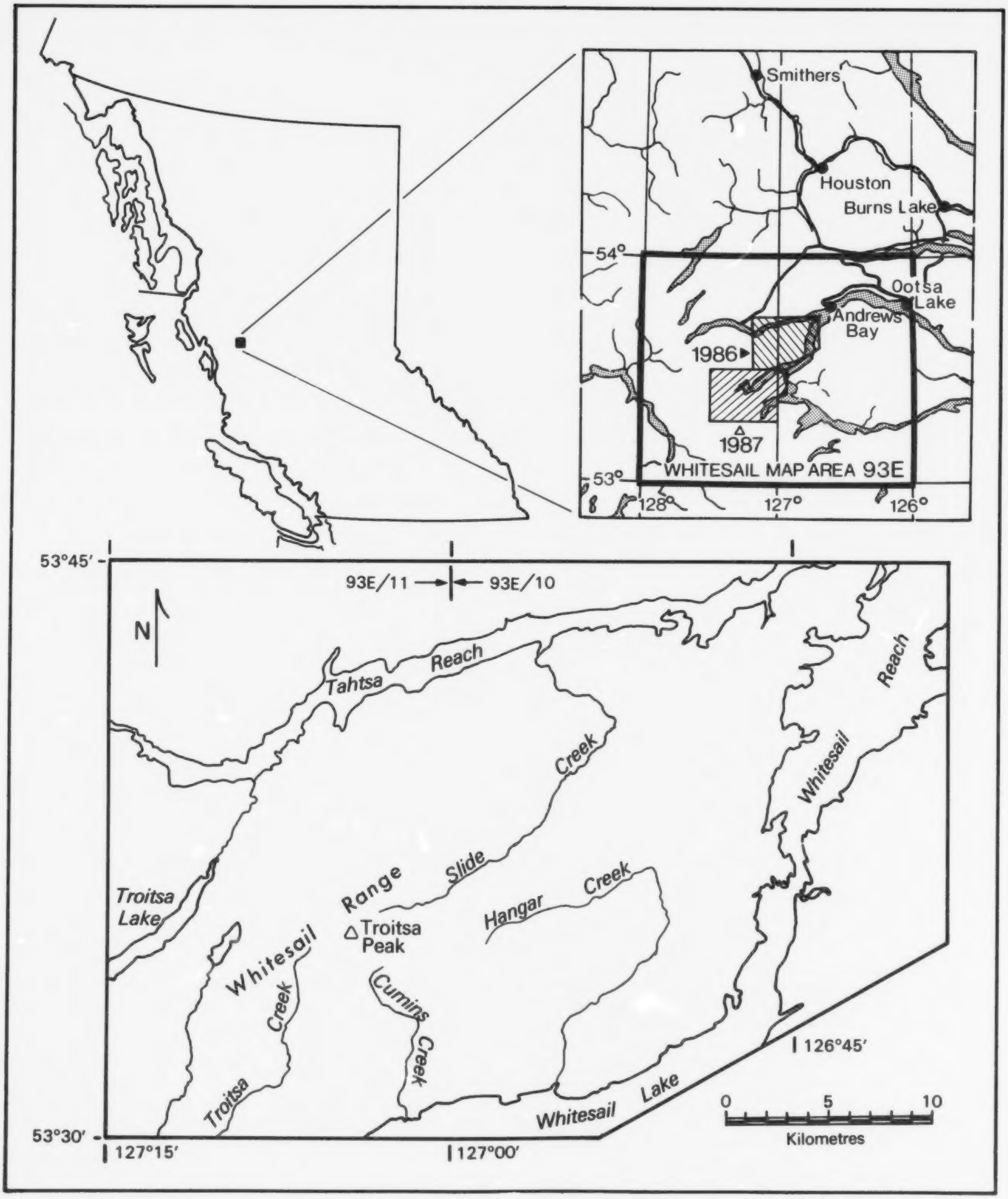
Smithers
Houston
Burns Lake
54°
Ootsa Lake
Andrews Bay
1986
1987
WHITESAIL MAP AREA 93E
53°
128°
127°
126°
53°45′
93E/11
93E/10
N
Tahtsa Reach
Creek
Reach
Whitesail
Troitsa Lake
Range
Slide
Hangar Creek
Troitsa Peak
Whitesail
Creek
Cumins Creek
Troitsa
126°45′
Whitesail Lake
0
5
10
Kilometres
53°30′
127°15′
127°00′

Figure 3-5-1. Location map and physiography of the study area.

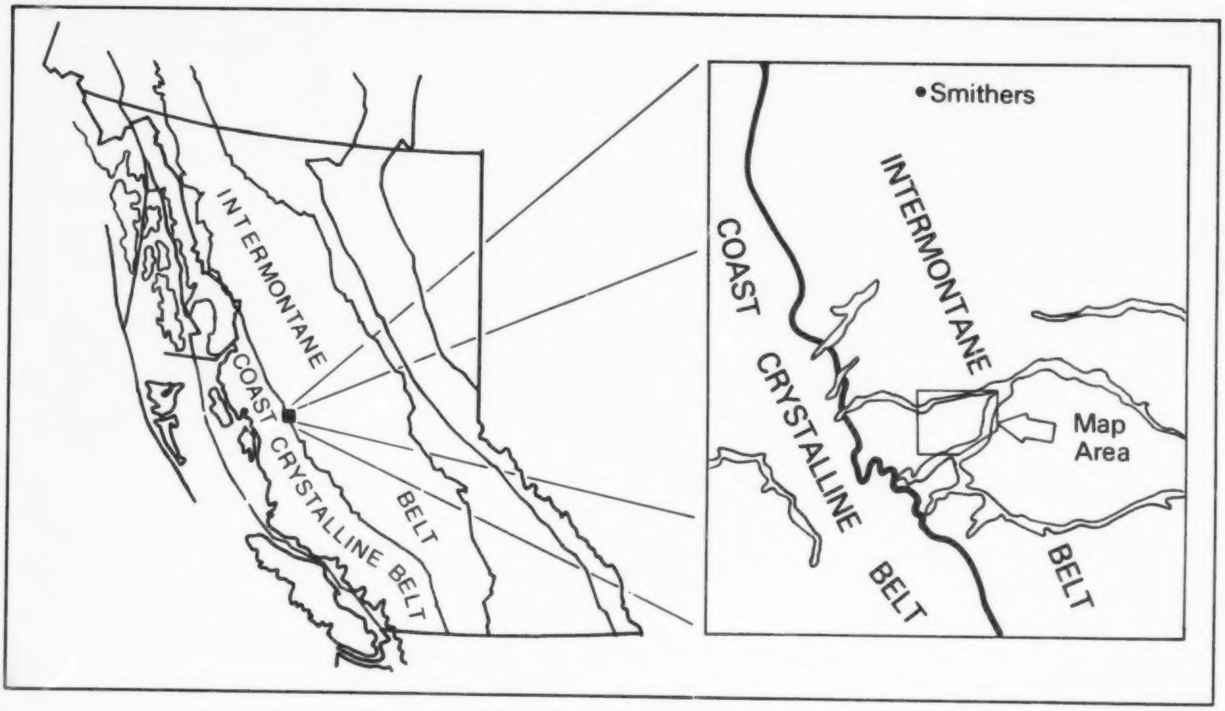

Figure 3-5-2. Tectonic setting of the study area.

In thin section arkosic rocks contain 30 to 80 per cent euhedral feldspar mixed with subrounded volcanic granules. The preponderance of feldspar suggests a nearby source; these rocks are probably derived from exposed Telkwa volcanics.

Shallow-marine fossils, including brachiopods, pelecypods, belemnites, gastropods and ammonites, are found in siltstone beds. Ammonites in particular have been useful in assigning a Middle Toarcian to Early Bajocian age to these strata (H.W. Tipper and R.L. Hall, personal communication, 1986; Figure 3-5-5). The Smithers Formation is defined by Tipper and Richards (1976) as Middle Toarcian to Early Callovian in age.

Unit 2A

Red and green lapilli tuff and tuffite have a gradational contact with underlying feldspathic sandstone and pebble conglomerate southwest of Troitsa Peak. These rocks comprise at least 800 metres of massive beds 50 centimetres to 10 metres thick. Accretionary lapilli occur within thinly laminated and graded beds 25 centimetres thick. The fragments in tuffs are angular to subrounded and have an aphanitic basaltic appearance. These rocks represent a transition from early shallow marine sedimentary deposition to later subaerial volcanism during Smithers time.

ASHMAN FORMATION (UNIT 3)

The Ashman Formation is exposed in one creek valley southeast of Troitsa Peak. The rocks are typically medium to thickly bedded siltstone, chert pebble conglomerate, coarse sandstone and shale. These lithologies closely resemble the Smithers Formation, making a positive identification difficult. Fossil fauna indicates a Late Bathonian to Callovian age (H.W. Tipper, personal communication, 1986; Figure 3-5-5).

LOWER CRETACEOUS ROCKS

SKEENA GROUP (UNIT 4)

Rocks of the Skeena Group were not identified in the study area. Extensive exposure of these rocks is found near Tahtsa Reach and Tahtsa Lake. The reader is referred to MacIntyre (1985) for a description of lithologies characterizing the Skeena Group in these areas.

UPPER CRETACEOUS (?) AND LOWER TERTIARY

OOTSA LAKE GROUP

The Ootsa Lake Group was proposed by Duffell (1959) for rhyolitic flows and less voluminous basalt, andesite, and pyroclastic and sedimentary rocks exposed at Ootsa Lake. A Late Cretaceous to Early Tertiary age is inferred from shelly fauna and plant debris found in conglomerate near the base. Similar lithologies occupy much of the Whitesail Range and underlie the low terrain adjacent to Whitesail Reach and the eastern end of Tahtsa Reach. Within the study area, the Ootsa Lake Group is subdivided into six rock units on the basis of outcrop appearance and lithology. These rocks rest with angular discordance on Lower to Middle Jurassic Smithers Formation. Age determinations on four volcanic units are currently in progress.

Andesitic Flows (Unit 5)

Andesitic flows containing several per cent biotite phenocrysts represent the lowest stratigraphic rock unit of the Ootsa Lake Group in Whitesail Range. These lavas comprise the base of a layered volcanic sequence in the northern Whitesail Range. The lower contact is not exposed, however a minimum thickness of 200 metres

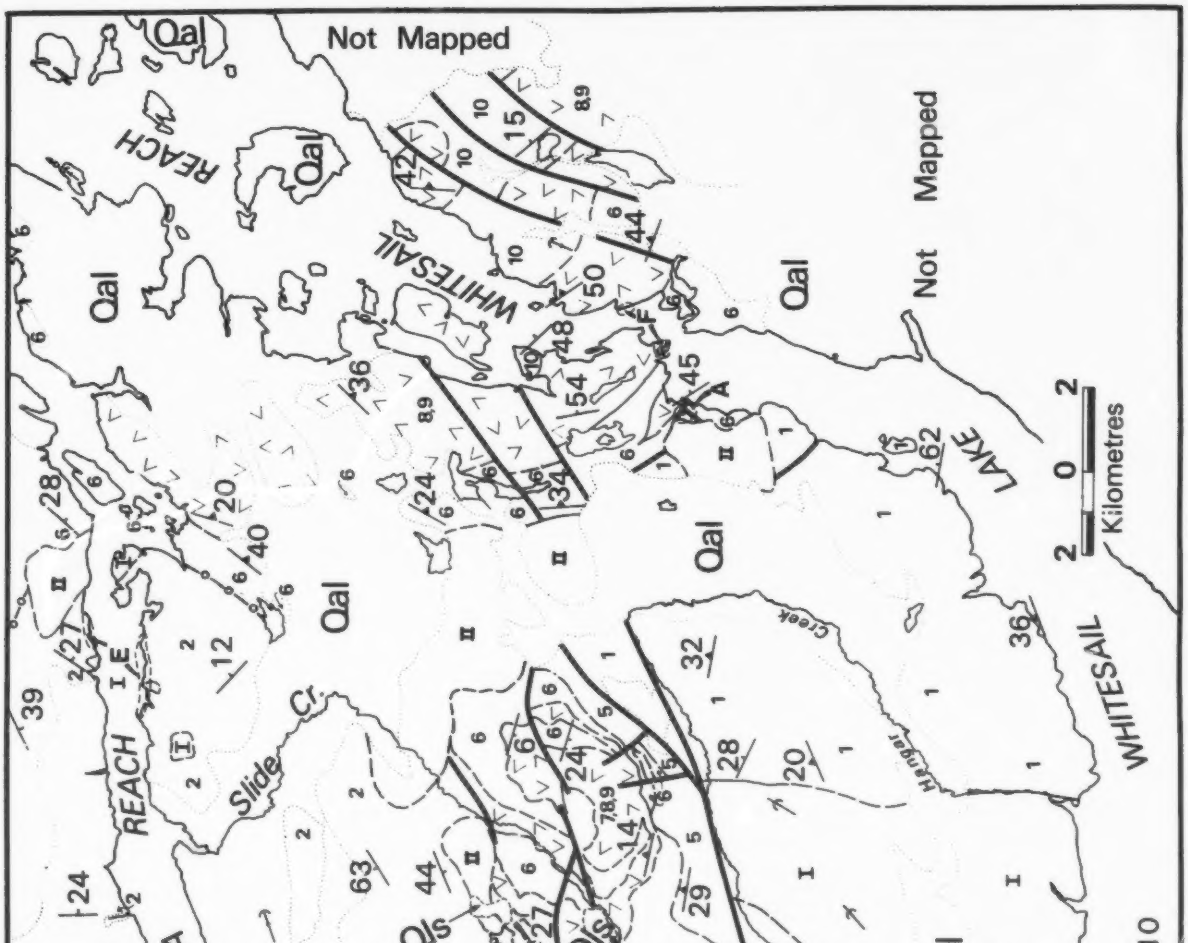
Not Mapped
Not Mapped
Qal
Qls
REACH
WHITESAIL
TAHTSA
Slide Cr.
Creek
Cumins
Troitsa
WHITESAIL
LAKE
53°45′
127°00′
93E/11
93E/10
N
2
0
2
Kilometres
A
B
C
D
E
F

Figure 3-5-3. General geology of Whitesail Lake area, west-central British Columbia.

LEGEND

QUATERNARY

Qal	*Glacial till and alluvium*
Qls	*Landslide*

UPPER CRETACEOUS (?) AND TERTIARY

OOTSA LAKE GROUP

10	*Polymictic conglomerate, minor sandstone*
9	*Andesitic flows; 2 to 5 per cent biotite and hornblende phenocrysts*
8	*Rhyolitic flows and autoclastic breccia; sparse biotite phenocrysts*
7	*Andesitic flows and black vitrophyric flows interlayered with lahar*
6	*Basaltic flows, containing coarse-grained augite and plagioclase phenocrysts, interflow breccia, debris flows and air-fall crystal ash tuff*
5	*Andesitic flows containing 1 to 2 per cent biotite phenocrysts, local flow-banded andesite interbedded with lapilli ash tuff; unconformably overlies Jurassic rocks*

LOWER CRETACEOUS

SKEENA GROUP

4	*Micaceous sandstone, pebble conglomerate and shale*

MIDDLE JURASSIC

BOWSER LAKE GROUP

3	*ASHMAN FORMATION: Siltstone, shale and arkosic wacke; fossiliferous*

LOWER TO MIDDLE JURASSIC

HAZELTON GROUP

2b	*SMITHERS FORMATION: Lapilli tuff; gradational contact with unit 2a*
2a	*Siltstone, arkosic sandstone and conglomerate, minor chert, shale and limestone; fossiliferous*
1	*TELKWA FORMATION: Andesitic and lesser rhyolite flows, tuff and breccia, minor epiclastic interbeds*

INTRUSIVE ROCKS

EARLY TERTIARY

III	*Coarse-grained feldspar porphyry, probable feeders to unit 6 flows; porphyritic quartz-biotite-feldspar plugs and dykes*

LATE CRETACEOUS

II	*Porphyritic biotite-hornblende diorite, equigranular quartz diorite and gabbro*
I	*Granite, syenite, granodiorite and monzodiorite; equigranular to locally pegmatitic*

SYMBOLS

Unconformity; defined, assumed ....

Flow layering; inclined ....

Glacial ridge, striae ....

Veins and alteration ....

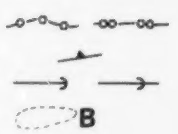

Figure 3-5-3a. Legend for Figure 3-5-3.

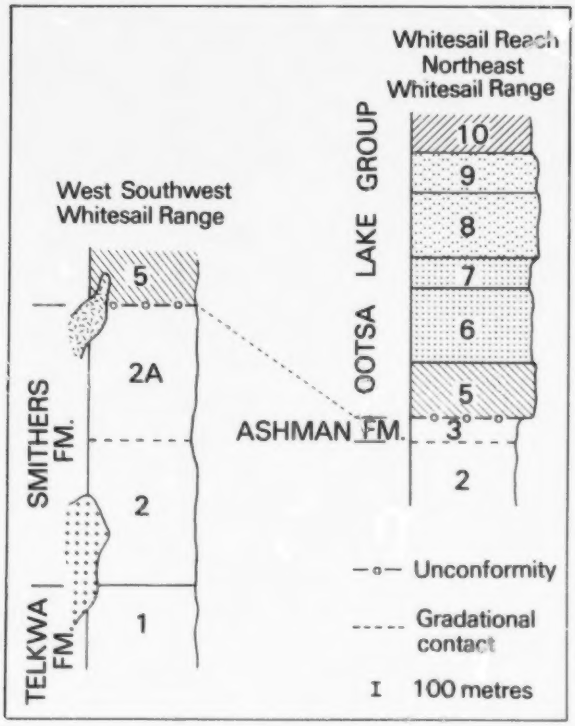

Figure 3-5-4.
Composite stratigraphic column for the Whitesail Lake area.

is estimated. The flows are mauve in colour and exhibit flow layering defined by aligned plagioclase and up to 2 per cent biotite phenocrysts. The mineral lineation imparts a slabby parting in outcrops.

Lapilli tuff and tuff breccia containing biotite-bearing fragments form subtly layered deposits, which in places interfinger with laminated grey flows lacking biotite phenocrysts. These rocks are gently inclined and rest with a profound angular unconformity on steeply dipping beds of the Smithers Formation near Troitsa Peak. The tuffs are commonly composed of subangular rhyolitic fragments which contain biotite phenocrysts set in a green chloritic matrix.

Amygdaloidal Basalt Flows (Unit 6)

Basalt flows have a sharp lower contact with Unit 5 northeast of Troitsa Peak. This contact is not exposed between Whitesail Lake and Tahtsa Reach, but it is thought to be an unconformity with Jurassic rocks. Conglomerate, which may mark the unconformity, is reported by Duffell (1959) underlying basalt on the eastern shore of Whitesail Lake. These exposures are now submerged.

The basalt flows attain a thickness of more than 425 metres. Individual flows range from 2 to 5 metres thick, and commonly are separated by oxidized interflow breccia as thick as 3 metres. Debris flows composed of rounded basaltic blocks up to 1.5 metres in diameter constitute deposits of variable thickness, interlayered with basalt. These rocks are more than 100 metres thick east of Troitsa Peak, but they thin rapidly to the west and north.

The flows are characteristically dark green to grey. Their texture varies from amygdaloidal porphyry to massive and aphyric. The porphyritic flows commonly contain coarse-bladed plagioclase up to 3 centimetres long and augite from 2 to 6 millimetres long. Most flows are highly vesiculated with agate, calcite and chabazite infilling vesicles.

Airfall crystal ash tuff, containing platy plagioclase 2 centimetres in diameter, forms a recessive marker bed within the basalt flows. This deposit is distinctly layered and ranges from 2 metres to more than 50 metres thick. Tree fragments found in the tuff near the top of the basalt unit suggest it is locally a subaqueous deposit.

Andesitic Flows (Unit 7)

Andesitic flows, vitrophyric flows and debris flows are about 200 metres thick in the northern Whitesail Range where they have a sharp contact with basaltic flows of Unit 6. Andesitic flows at the base of the sequence have a pronounced slabby parting developed parallel to flow layering. This primary layering is accentuated by sparse plagioclase phenocrysts 2 to 5 millimetres long set in a brown aphanitic matrix. Microscopically these flows contain phenocrysts of plagioclase, augite and scarce hornblende and biotite. The groundmass is composed of plagioclase microlites with trachytic texture and iron oxide granules.

The vitrophyric flows are typically black vitreous beds up to 10 metres thick. Their texture varies from sparsely porphyritic to massive and less commonly vesicular and coarsely porphyritic. In some sections fine-grained lithic fragments and fiamme-like structures are easily confused with collapsed pumice in welded ash flow deposits. In thin section, euhedral plagioclase phenocrysts are set in flow-laminated glass that often has a perlitic texture.

The debris flows form lenticular deposits more than 50 metres thick, occupying channels cut through vitrophyric flows. They are characterized by unstratified, poorly sorted rounded blocks derived mainly from vitrophyric flows.

Rhyolitic Flows (Unit 8)

Homogeneous rhyolitic flows more than 400 metres thick and characterized by sparse biotite phenocrysts, overlie basalt flows of Unit 6 between Tahtsa Reach and Whitesail Reach. Similar rocks, more than 150 metres thick, have an abrupt contact with Unit 6 and Unit 7 in the northern Whitesail Range. The rhyolite flows form cliffs with a massive, rusty weathered appearance. The rocks are pink, brownish-red or grey in colour. Most exposures exhibit a conspicuous bedding plane parting, flow layering, aligned phenocrysts, and uncommonly spherulites and mariolitic cavities. Petrographically, plagioclase is the dominant phenocryst, potassium feldspar and biotite are subordinate. The matrix commonly has a pilotaxitic texture.

Breccia bodies composed entirely of rhyolite fragments occur as thin irregular deposits presumably marking the top or front of flows. Elsewhere monolithic breccia is confined to discordant zones 75 centimetres to more than 3 metres wide. These breccia occurrences are thought to have formed during degassing of thick flows, since there is no evidence for shear-related movement.

Andesitic Flows (Unit 9)

Andesitic flows, characterized by 2 to 5 per cent biotite phenocrysts, have a sharp lower contact with Unit 8 at Whitesail Reach. This rock weathers to massive light pinkish-red blocks. Aphanitic fragments with wispy outlines are ubiquitous and resemble eutaxitic texture developed in ash flow deposits. In thin section, the fragments are not shards, but consist of fine fluidal banded glass that has undergone variable amounts of devitrification. Plagioclase and biotite are the dominant phenocrysts comprising up to 40 per cent of the rock, augite and hornblende occur in trace amounts. Locally a brownish-red laminated vitrophyric flow about 1 metre thick, with or without spherulites, is found at the base of Unit 9.

Conglomerate (Unit 10)

Conglomerate constitutes the youngest unit mapped in the study area. This unit is localized at Whitesail Reach where it rests on the eroded top of Unit 9. The conglomerate is composed of rounded to

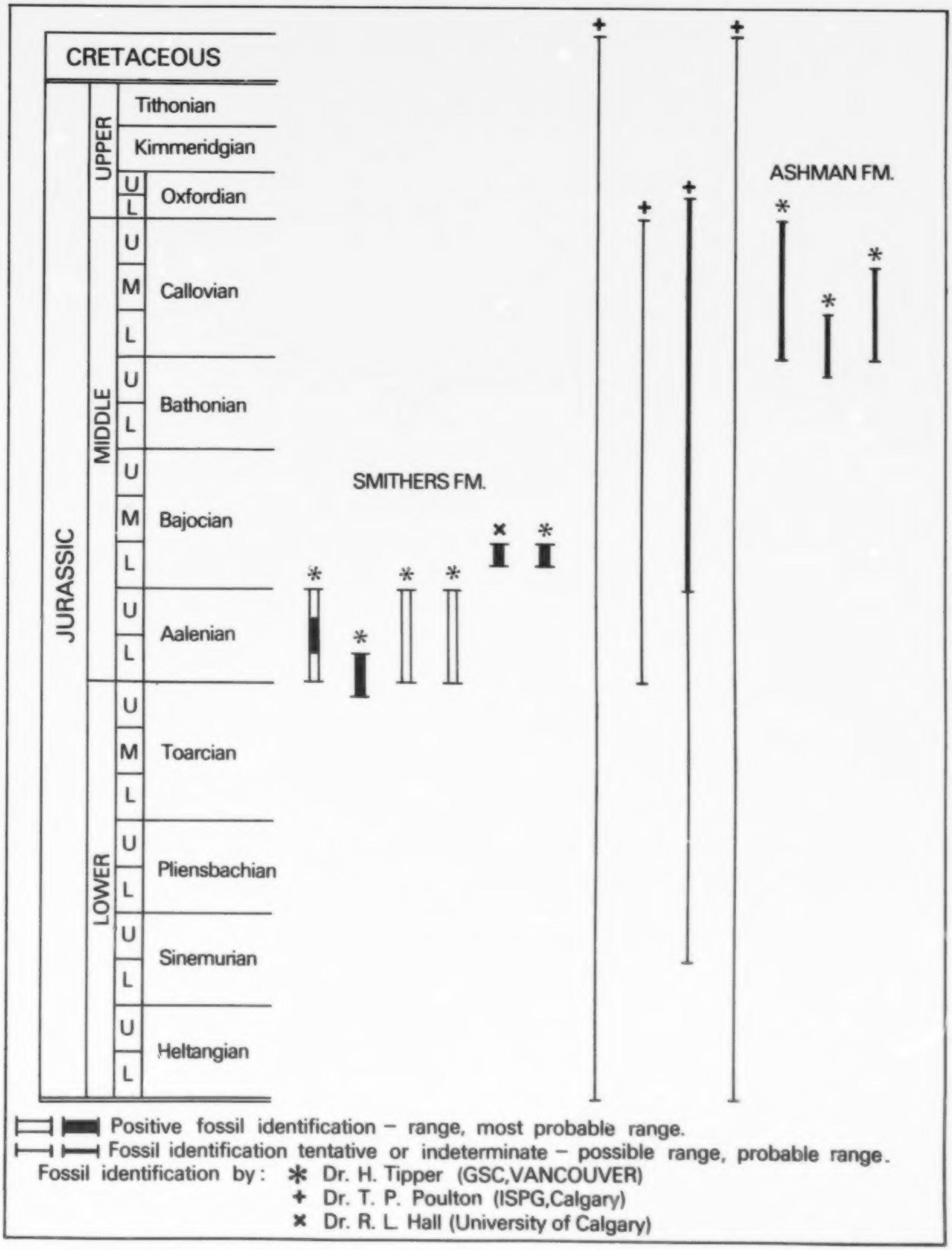

Figure 3-5-5. Ages of fossil fauna from the Smithers Formation and Ashman Formation, Whitesail Lake area.

subangular clasts that range from several centimetres to about 1 metre in diameter. The majority of clasts are derived from flows of Unit 8 and Unit 9. A few basaltic clasts resemble Unit 6 and locally quartz phyric rhyolite clasts are prominent. The conglomerate is poorly sorted and unstratified, but contains layered sand to granule-sized clastic interbeds as thick as 45 centimetres. Plant debris, tree fragments and amber are found within the finer clastic beds.

INTRUSIVE ROCKS

Intrusive rocks in the Whitesail Lake area include stocks and cupolas of granite, syenite, granodiorite, diorite and gabbro. The largest of the intrusive bodies underlies about 32 square kilometres between Cummins Creek and Hangar Creek. The contacts are generally sharp and contact metamorphism is negligible. The rock is red to pink, coarse-grained, equigranular granite and syenite.

On Tahtsa Reach a similar syenitic rock is locally pegmatitic on the margin of an intrusion that grades inwards to a gabbroic core. The core zone is medium-grained and consists of plagioclase and interstitial augite. A broad area of pervasive hydrothermal alteration affects Smithers Formation host rocks near this intrusion.

Porpnyritic hornblende-biotite granodiorite and a dioritic intrusion occupy the central part of the map area. The porphyritic stock contains euhedral plagioclase averaging 5 millimetres long and 3 to 5 per cent combined biotite and hornblende. The dioritic body near the west shore of Whitesail Lake is a medium-grained equigranular rock which has *en échelon* quartz veins occurring adjacent to a sharp northeast contact.

Near Troitsa Peak a group of porphyritic hypabyssal plugs intrudes and locally alters the basal unit of the Ootsa Lake Group. These rocks are typically dark green and contain plagioclase phenocrysts varying from 0.8 to 2.5 centimetres long. They are thought to be the intrusive equivalents of flat-lying columnar-jointed flows capping Troitsa Peak. These flows in turn are probably temporally related to the coarse phyric flows characteristic of Unit 6.

The ages of intrusive rocks in the area are undetermined, but they are assumed to be correlative with the late Cretaceous and early Tertiary Bulkley and Coast intrusions.

STRUCTURE

A combination of folds and faults controls the present distribution of rocks in the Whitesail area. Rocks of the Ootsa Lake Group at Whitesail Reach and in the Whitesail Range appear to be preserved within the synclinal hinges of gentle open folds. The axes of these folds trend north to northeasterly. Folds that deform Smithers Formation sediments west of Troitsa Peak also trend northeast. They are generally open and locally tightly appressed and overturned. In contrast, the overlying Ootsa volcanics are only gently warped. It is uncertain whether this variation in fold style reflects one or more phases of deformation.

Faults disrupt the Telkwa volcanics through to the youngest Ootsa strata. They have a dominant northeast trend, however some trend more northerly. The faults are generally steeply inclined with normal movement.

Locally faults delimit downdropped and tilted blocks, preserving younger strata. The thick section of Ootsa Lake Group rocks exposed in the Whitesail Range is thought to be preserved within a downdropped block that is juxtaposed against a block of exhumed Telkwa volcanics. A similar pattern of block faults is evident in the western Whitesail Range where west-side-down displacement preserves and apparently thickens east-dipping Smithers strata.

MINERAL PROSPECTS

Mineral prospects in the study area are categorized according to their morphology and structural setting. Two potential exploration targets with features common in an epithermal-mesothermal gold-silver setting are recognized:

(1) Fracture and shear-controlled veins,

(2) Pervasive clay-silica-pyrite ± barite replacing country rock near intrusions.

VEIN OCCURRENCES

Quartz veins with anomalous gold geochemistry occur on the west shore of Whitesail Lake and at Cummins Creek. At Location A (Figure 3-5-3) quartz veins are hosted by Smithers Formation sedimentary rocks in contact with a dioritic intrusion. Individual veins range in width from 1 millimetre to 15 centimetres, strike between 120 and 160 degrees and dip steeply. Arsenopyrite and pyrite are present in grey-black quartz veins and in silicified breccia. Chip samples of a quartz vein 10 centimetres wide and a breccia zone 50 centimetres wide returned gold analyses of 584 and 4400 parts per billion (ppb), respectively; silver was not detected. The veins have been tested by 13 drill holes; a best intercept returned an assay of 2.80 grams per tonne gold over 3.9 metres (Goad and Harris, 1983).

At Cummins Creek *en échelon* quartz veins trending roughly 170 degrees cut Telkwa volcanic rocks (Location B, Figure 3-5-3). The veins range in width from several centimetres to 1.5 metres and are traceable intermittently for up to 35 metres along strike. Pyrite and trace amounts of galena are found in white quartz and gold analyses ranging up to 1800 ppb have been reported (Cawthorn, 1982).

PERVASIVE HYDROTHERMAL ALTERATION

Broad areas of clay minerals, fine-grained silica, pyrite and in places, barite, variably replace Smithers Formation sediments and Ootsa Lake Group volcanics over broad areas at Locations C, D, E and F (Figure 3-5-3).

Exposures of altered rock are commonly cream-white and weather to rusty fragments. The primary texture is obscured by secondary clay minerals and cryptocrystalline silica which imparts a homogeneous porcelaneous appearance to the rocks. Pyrite is ubiquitous and occurs as fine-grained disseminations and euhedral crystals. In several localities coarsely crystalline barite occupies fractures and cements breccia fragments in zones of pervasive alteration.

Pervasive alteration is spatially associated with high-level plutons at Tahtsa Reach (Location E) and near Troitsa Peak (Location C). Similar alteration at Location D cannot be related to an intrusion exposed nearby, however interestingly the three alteration zones occur at or close to the unconformity. Bleaching is widespread in rhyolitic flows near the south end of Whitesail Reach (Location F). This alteration is probably related to granitic rocks noted in a former canyon at this location (Galloway, 1916). Marshall (1925) reported specks of free gold, with pyrite and chalcopyrite, in highly altered rhyolites at a site closely corresponding with Location F.

ANALYTICAL RESULTS

Quartz veins and zones of argillic alteration were chip sampled at 37 sites. Each sample was analysed for gold, silver, mercury, arsenic, antimony and barium. The location of sample sites will be plotted on the alteration-mineral occurrence map scheduled for release in January 1987. The analytical results are summarized below:

(1) Gold in most samples is lower than a detection limit of 30 ppb, however values of 220, 659, 584 and 4400 ppb were obtained from three separate veins.

(2) Silver analyses are consistently less than 14 parts per million (ppm). The highest concentration of 123 ppm corresponds with a zone of argillic alteration.

(3) Mercury concentrations range from less than 20 ppb to about 2900 ppb. Groups of anomalous mercury values occur within broad areas of pervasive argillic alteration.

(4) Arsenic concentrations vary directly with mercury in altered rocks, but are negligible in most veins.

(5) Antimony is invariably below a detection limit of 10 ppm.

(6) Barium analyses are not yet available and will be reported at a later date.

CONCLUSIONS

The general stratigraphic section in the Whitesail area has a base of volcanic and shallow marine sedimentary rocks of the Lower to Middle Jurassic Hazelton Group. The sedimentary member of the Smithers Formation is nearly identical to the Ashman Formation of the Bowser Group. These formations cannot be adequately separated on the basis of lithology.

The Ootsa Lake Group lies above an angular unconformity. It is a sequence dominated by subaerial flows ranging in composition from basalt to rhyolite. The lack of epiclastic and pyroclastic rocks interlayered with the flows indicates volcanism was continuous. These rocks probably represent weak eruptions associated with small composite cones and exogenous domes.

The regional structure in the study area is characterized by gentle folding about north-trending axes that probably reflects deformation associated with the Pacific Orogen. Rocks of the Ootsa Lake Group are disrupted by northeast-trending faults. They are preserved in the troughs of broad open folds and in a tilted block bounded on one side by a fault.

Quartz veins, containing arsenopyrite, pyrite and minor base metals together with areas of pervasive hydrothermal alteration characterized by clay minerals-silica-pyrite ± barite, are potential exploration targets for epithermal to mesothermal gold-silver mineralization. The veins occur in extensional fractures near stocks or in areas with no apparent relationship with intrusive rocks. A close spatial association exists between zones of pervasive alteration, intrusions and the unconformity separating Jurassic and Tertiary volcanic rocks.

ACKNOWLEDGMENTS

The progress of mapping was augmented by the enthusiasm and diligence of assistants John Drobe and Ashley Bansgrove.

Knowledge of the regional geology and mineral occurrences is complemented through discussion and information provided by Drs. D.G. MacIntyre, T. Richards and G. Woodsworth. The assistance of Drs. H.W. Tipper, T.P. Poulton and R.L. Hall in promptly identifying fossils is gratefully acknowledged.

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GEOLOGY OF THE AREA AROUND THE MIDWAY DEPOSIT NORTHERN BRITISH COLUMBIA*
(104O/16)

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and
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INTRODUCTION

The Midway silver-lead-zinc manto deposit is located in map area 104O/16, 10 kilometres south of the British Columbia-Yukon border and approximately 80 kilometres west of Watson Lake, Yukon (Figure 3-6-1). Access is by means of a 23-kilometre gravel road that leads south from Milepost 701 on the Alaska Highway. Truck bridges span the Rancheria and Tootsee Rivers.

This report presents the results of a geologic mapping project conducted between June 9 and August 28, 1986. Four 1:25 000-scale open file geologic maps covering 104O/16 are being prepared; these will be released in January 1987. This season's mapping was the initial phase of a four-year project funded by the Canada/British Columbia Mineral Development Agreement; the project will cover an area extending from the Yukon border to Cassiar.

Objectives of the study are as follows:

(1) To map the geology in detail and determine the settings and controls of known mineral deposits.

(2) To identify structural/stratigraphic settings that are likely to host Midway-type manto deposits.

(3) To map the Sylvester Allochthon in terms of significant lithotectonic subunits, to identify those subunits within it that are favourable for Erickson-type gold-quartz occurrences and to evaluate the asbestos potential of Sylvester ultramafite bodies.

(4) To investigate other potential metallic or nonmetallic resources.

GEOLOGY

The Midway area lies within the Cassiar Platform, a splinter of the North American continental shelf that was carried perhaps 750 kilometres to the northwest outboard of the dextral Tintina fault (Gabrielse, 1985). Miogeoclinal strata ranging from Lower Cambrian to Lower Mississippian (Figure 3-6-3) form the footwall of a regional bedding-parallel thrust (Figure 3-6-2). The hangingwall of the thrust is the Sylvester Allochthon, an internally imbricated suite of oceanic upper and lower crustal rocks and ultramafites. Fossil ages so far obtained from the Sylvester Allochthon in the Cry Lake and McDame map areas range from Late Devonian to Late Triassic (Gordey *et al.*, 1982; Harms, 1986). Emplacement of the allochthon occurred between Late Triassic and mid-Cretaceous time. In the McDame map area the predominantly mid-Cretaceous Cassiar batholith intrudes the Sylvester Allochthon. This relationship is not seen in 104O/16, where Cassiar intrusions cut only miogeoclinal rocks. Northwest-trending mylonitic zones are developed within the batholith. Potassium-argon ages from mylonites collected near map area 104O/16 suggest mid to Late Cretaceous transcurrent displacement.

MIOGEOCLINAL STRATA

UNIT 1 — ATAN GROUP (LOWER CAMBRIAN)

The oldest strata exposed in map sheet 104O/16 correlate with the Atan Group, which, in the McDame map area, has been subdivided into the lower, dominantly siliciclastic Boya Formation (1A) and the upper carbonate-dominated Rosella Formation (1B) (Fritz, 1980). Exposure of Atan Group rocks in 104O/16 is restricted to fault-bounded panels in the area immediately west of the Cassiar batholith (Figure 3-6-2).

The Boya Formation is dominated by siliciclastic rocks — well-sorted white, grey and black quartzites with muscovitic partings and poorly sorted, characteristically black turbiditic deposits. The turbidites range from black slate through thin-bedded siltstone to quartzose greywacke and quartz-pebble conglomerate. Streaky grey and black limestone beds up to 15 metres thick occur sporadically within the siliciclastic sequence. The Rosella Formation consists predominantly of streaky grey limestone or marble and orangey-buff-weathering dolomite; individual beds are generally greater than 100 metres thick. The top and, in most cases, the bottom of the Rosella Formation are either unexposed or truncated by intrusive contacts or faults. In some areas (south of Tootsee Lake, on the ridge southeast of the Amy property, and in drill core on the Silverknife property) thin-bedded argillite, hornfels or phyllite comprise up to 15 per cent of the Rosella Formation. At the southern "bend" of the Tootsee River, a platy limestone 100 metres thick separates black pyritic argillite assigned to the Boya Formation from thin-bedded calc-silicates and phyllite. The limestone and the thin-bedded units are assigned to the Rosella Formation. Pure marble is intercalated with thin-bedded calc-silicates in Silverknife drill core.

Rosella Formation carbonates host manto or replacement sulphide mineralization on the Silverknife claims (Mineral Inventory 104O-048) in British Columbia and also at the Butler Mountain occurrence in the Yukon.

UNIT 2 — KECHIKA GROUP (CAMBRIAN-ORDOVICIAN)

Thin-bedded calcareous shales and siltstones with minor thin pure limestone interbeds occur in fault-bounded slices along Big Creek in the northeast corner of the map area. They weather silvery to light yellowish or orange, and are characteristically strongly deformed and cut by small-scale internal thrusts or décollements.

These rocks correlate with the Kechika Group as described in the McDame map area (Gabrielse, 1963). Exposures of thin-bedded calc-silicate and biotite hornfels in contact with the Cassiar batholith in the northwest quarter of the area, and on Canamax' Heap claims east of the Ewen Barite road, are also included in the Kechika Group.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

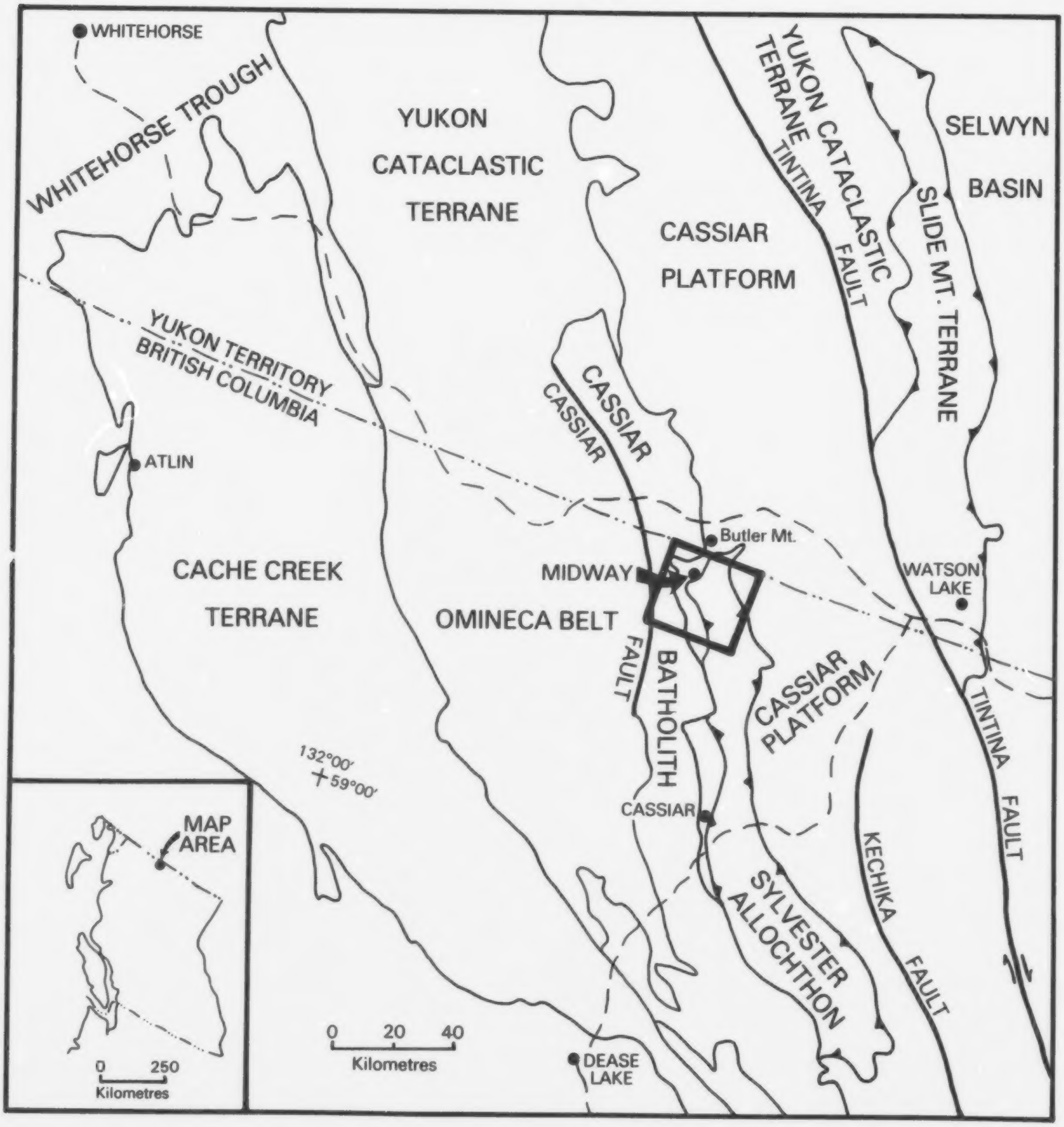
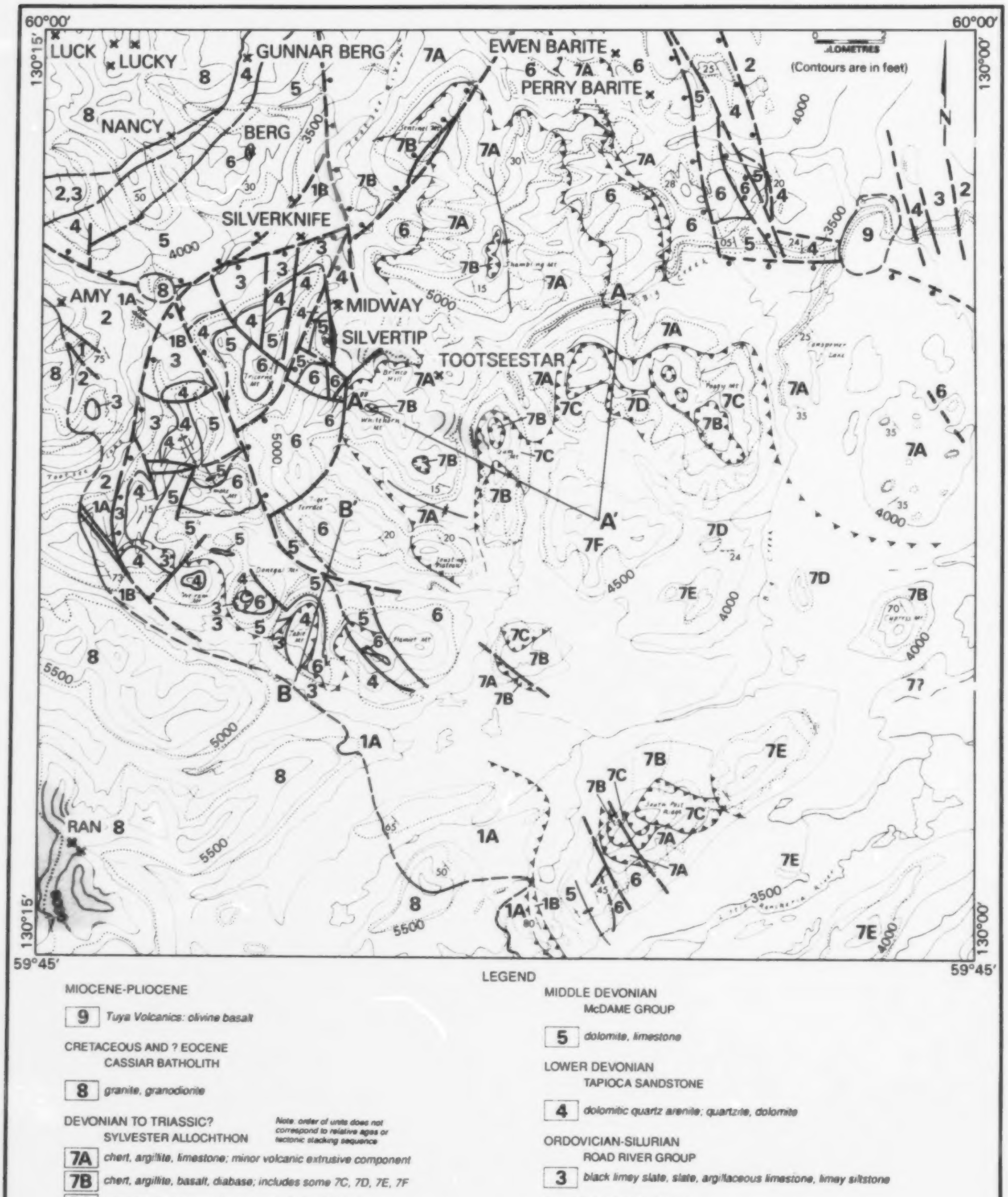

WHITEHORSE
WHITEHORSE TROUGH
YUKON CATACLASTIC TERRANE
CASSIAR PLATFORM
YUKON CATACLASTIC TERRANE
TINTINA FAULT
SLIDE MT. TERRANE
SELWYN BASIN
YUKON TERRITORY
BRITISH COLUMBIA
CASSIAR
CASSIAR
ATLIN
Butler Mt.
MIDWAY
CACHE CREEK TERRANE
OMINECA BELT
FAULT
BATHOLITH
WATSON LAKE
CASSIAR PLATFORM
TINTINA FAULT
132°00′
59°00′
CASSIAR
MAP AREA
SYLVESTER ALLOCHTHON
KECHIKA FAULT
0
250
Kilometres
0
20
40
Kilometres
DEASE LAKE

Figure 3-6-1. Location of map sheet 104O/16.


60°00′
130°15′
LUCK
LUCKY
GUNNAR BERG
EWEN BARITE
PERRY BARITE
KILOMETRES
(Contours are in feet)
N
130°00′
NANCY
BERG
SILVERKNIFE
AMY
MIDWAY
SILVERTIP
TOOTSEESTAR
RAN
A
A′
B
B′
1A
1B
2
2,3
3
4
5
6
7A
7B
7C
7D
7E
7F
7?
8
9
3500
4000
4500
5000
5500
59°45′

LEGEND

MIOCENE-PLIOCENE

9	*Tuya Volcanics: olivine basalt*

CRETACEOUS AND ? EOCENE
CASSIAR BATHOLITH

8	*granite, granodiorite*

DEVONIAN TO TRIASSIC?
SYLVESTER ALLOCHTHON

Note: order of units does not correspond to relative ages or tectonic stacking sequence

7A	*chert, argillite, limestone; minor volcanic extrusive component*
7B	*chert, argillite, basalt, diabase; includes some 7C, 7D, 7E, 7F*
7C	*serpentinite; may contain blocks of all other lithologies*
7D	*coarse-grained, in part foliated, gabbro, locally brecciated and/or cut by dykes*
7E	*trachyandesite flows, subvolcanic intrusives, pyroclastic to epiclastic sediments*
7F	*zoned hornblende gabbro-tonalite-granodiorite complex*

DEVONIAN-MISSISSIPPIAN
EARN GROUP

6	*slate, siltstone, greywacke, chert-pebble conglomerate*

MIDDLE DEVONIAN
McDAME GROUP

5	*dolomite, limestone*

LOWER DEVONIAN
TAPIOCA SANDSTONE

4	*dolomitic quartz arenite; quartzite, dolomite*

ORDOVICIAN-SILURIAN
ROAD RIVER GROUP

3	*black limey slate, slate, argillaceous limestone, limey siltstone*

CAMBRIAN-ORDOVICIAN
LOWER KECHIKA GROUP

2	*thin bedded limey slate, siltstone; limestone*

LOWER CAMBRIAN
ATAN GROUP

1B	*Rosella Formation: thick limestone, dolomite, shale, minor slate*
1A	*Boya Formation: quartzite, slate, siltstone, conglomerate, limestone*
■	*quartz-sericite alteration*

Figure 3-6-2. Geology and mineral deposits, map sheet 104O/16.

The Amy occurrence (MI 104O-004), a conformable silver-lead-zinc replacement deposit, is hosted by an anomalously thick (5 to 40 metres) limestone lens, probably a patch reef, in the Kechika Group.

UNIT 3 — ROAD RIVER GROUP (ORDOVICIAN-SILURIAN)

The Road River Group is exposed at the base of Tricorne Mountain, south and east of Tootsee Lake, in thrust sheets on Weirami, Donegal and Table Mountains, on the ridges northwest of the Tootsee River, and in fault slices along Big Creek. It consists of approximately 200 metres of very fissile black, graphitic limy slate and black argillaceous-graphitic limestone, with minor interlayers of black noncalcareous slate and pure dolomite. The uppermost part of the Road River Group, directly below the Tapioca sandstone, is a platy, grey graphitic siltstone that contains impressions of the graptolite *diplograptus* (?) that are up to 10 centimetres long. Isolated lenticular dark grey quartzite units, 1 to 10 metres thick and tens of metres long, occur in Road River exposures south of Tootsee Lake. They are probably the result of tectonic shredding of the base of the Tapioca sandstone, rather than a gradational Road River-Tapioca sandstone contact.

UNIT 4 — TAPIOCA SANDSTONE (LOWER DEVONIAN)

The Tapioca sandstone is an informal name proposed by Gabrielse (1969) for the rocks that lie stratigraphically between the Road River and McDame Groups (formerly Sandpile Group). The unit contains the diagnostic "tapioca" sandstone — quartz grains of high roundness and sphericity in a dolomite matrix — but also thick intervals of pure white, grey and black quartzite, and pure massive dolostone. In some areas the base of the Tapioca sandstone is quartzite in abrupt contact with sooty black Road River shale. In others (Table Mountain, Weirami Mountain, Donegal Mountain) the basal unit is a distinctive wavy bedded, light grey, buff-weathering, fine-grained, bioturbated dolomitic sandstone. This unit passes transitionally downwards into siltstone of the uppermost Road River Group.

The Tapioca sandstone passes transitionally upwards into laminated or massive dolostone. We place the Tapioca-McDame contact at the top of the highest significant sandy layer. It should be noted that laminated dolostones above the sandstones have been included within the Tapioca sandstone unit (Gabrielse, 1969); therefore the lowest part of the McDame Group in our mapping is the upper formation of the Tapioca sandstone as defined by Gabrielse (1969).

UNIT 5 — McDAME GROUP (MIDDLE DEVONIAN)

The McDame Group hosts manto silver-lead-zinc mineralization at Midway. The McDame is a platformal carbonate accumulation. Strong facies variations occur within it. McDame exposures in northwestern 104O/16 consist of lower dark grey, buff-weathering, laminated to massive, commonly fetid dolostone, overlain by dark grey, highly fossiliferous, locally platy limestone, which is dolomitized in part. Biostromal accumulation of *amphipora*, *thamnopora*, *stringocephalus*, *syringapora* and *stromatoporoids* indicate a flourishing fauna of relatively low diversity. Shallowing upward sequences are shown by local accumulations of cryptalgal laminites, stromatolites and *stromatotacti*, indicative of an intertidal to subtidal environment. *Amphipora*-rich limestones are also seen on Donegal Mountain, eastern Table Mountain and South Post Ridge.

In contrast, McDame exposures in the northeastern part of the area are wholly dolomitic and nearly barren of fossils. They show thin micritic bedding, rip-up clasts and sedimentary breccias, and may represent a nearshore high-energy environment. The top of the McDame on Hamlet Mountain and on the west side of Table Mountain is also unfossiliferous dolostone. Either local facies variations or significant differential erosion may account for the strong differences between these exposures and nearby exposures of *amphipora* limestones.

Two early phases of karsting affected the uppermost McDame. The earliest, pre-Earn, event is shown by irregular paleotopography, with up to 200 metres of relief, at the McDame-Earn contact. Depressions in the top of the McDame are commonly filled by rose, buff and silver-coloured dolomitic (?) porcelanous siltstones that are atypical of the Earn proper. The best exposed examples of this are in the vicinity of the Berg showing (MI 104O-015) and on Hamlet Mountain. Further solution collapse postdated Earn deposition but occurred before Mesozoic tectonism. On Donegal and Smoke Mountains, angular fragments of porcelanous black basal Earn shale occur in breccia at and below the McDame-Earn contact. None of these fragments show the fine crenulations that developed in nearly all Earn slates during the major deformational event. Karst features within the upper McDame include large (up to 3 metres diameter) tubes and cavities, particularly northwest of the Tootsee River, and brecciation accompanied by coarse dolomitization, best seen on Smoke Mountain. Solution breccias and spar-filled vugs are seen throughout the McDame.

Breccias consisting primarily of lowermost Earn slate clasts are abundant in the upper McDame in the vicinity of the Midway deposit. Most of these contain crenulated slate clasts and/or sulphide clasts; hydrothermal quartz forms the breccia matrix in some cases. A third solution event thus postdated Jurassic deformation, and probably accompanied mineralization. In this case, hydrothermal fluids rather than cold groundwater probably instigated solution collapse.

UNIT 6 — EARN GROUP (UPPER DEVONIAN-LOWER MISSISSIPPIAN)

This turbiditic sequence, formerly included in the lower Sylvester Group (Gabrielse, 1969), has been reassigned by Gabrielse (Gabrielse and Mansy, 1980; H. Gabrielse, personal communication, 1986) to the Earn Group, a lithologically similar package of roughly equivalent age that is recognized from MacMillan Pass in the Yukon to the Gataga area of British Columbia (Gordey *et al.*, 1982; McClay and Insley, 1986). The Earn Group includes black slate, thin-bedded siltstone, thin to thick-bedded sandstone, chert-pebble conglomerate, and volumetrically minor but economically significant baritic, siliceous and sulphide-rich exhalites that are accompanied in some instances by chert and limestone.

Cordilleran Engineering Ltd. has constructed a viable internal Earn stratigraphy in the vicinity of the Midway deposit: two broadly coarsening upward sequences with exhalative horizons concentrated in the lower half of the second fine-grained clastic sequence. Abrupt facies variations and lack of fossil control precluded development of Earn stratigraphy at the scale of mapping.

Black shales at the base of the Earn Group abruptly and unconformably overlie McDame carbonates. The Earn Group comprises the youngest autochthonous strata in map area 104O/16. Its upper contact is a thrust, the base of the Sylvester Allochthon.

THE SYLVESTER ALLOCHTHON (UNIT 7)

The Sylvester Allochthon is a pile of discrete lithotectonic units, which have been dismembered and tectonically interleaved. Some units are linked by pre-emplacement events, while others have nothing in common except their present proximity. The allochthon as a whole overrode the Earn Group along a planar master thrust that was subsequently deformed into open folds (Figures 3-6-2 and 3-6-4).

The allochthon has been subdivided by field mapping into six lithotectonic units (Figure 3-6-2) and 15 subunits (Table 3-6-1).

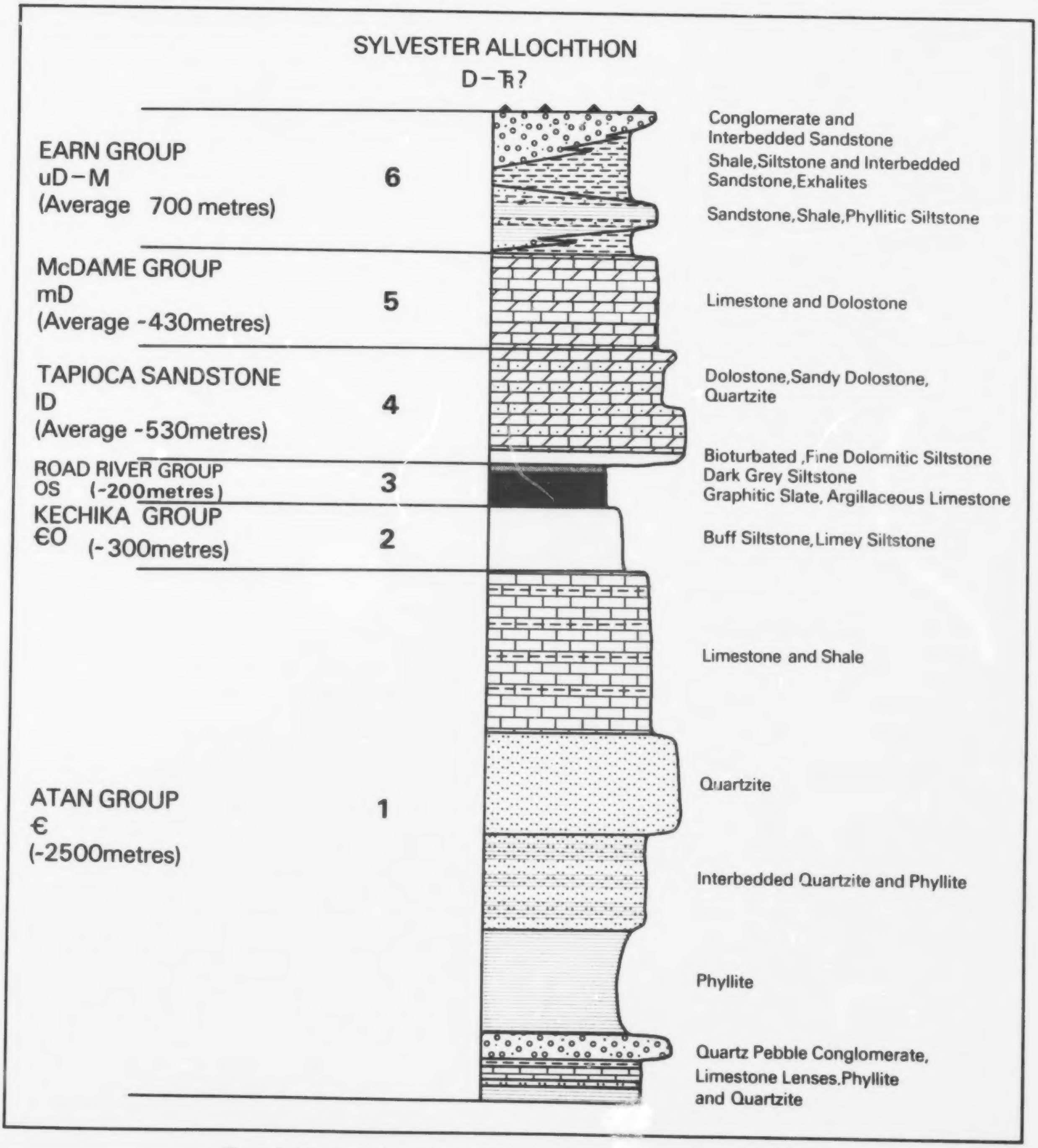

SYLVESTER ALLOCHTHON
D−Ꞧ?
EARN GROUP
uD−M
(Average 700 metres)
6
Conglomerate and Interbedded Sandstone
Shale,Siltstone and Interbedded Sandstone,Exhalites
Sandstone,Shale,Phyllitic Siltstone
McDAME GROUP
mD
(Average -430metres)
5
Limestone and Dolostone
TAPIOCA SANDSTONE
lD
(Average -530metres)
4
Dolostone,Sandy Dolostone, Quartzite
Bioturbated ,Fine Dolomitic Siltstone
ROAD RIVER GROUP
OS (-200metres)
3
Dark Grey Siltstone
Graphitic Slate, Argillaceous Limestone
KECHIKA GROUP
€O (-300metres)
2
Buff Siltstone,Limey Siltstone
Limestone and Shale
ATAN GROUP
€
(-2500metres)
1
Quartzite
Interbedded Quartzite and Phyllite
Phyllite
Quartz Pebble Conglomerate, Limestone Lenses,Phyllite and Quartzite

Figure 3-6-3. Geological columns of autochthonous units, map sheet 104O/16.

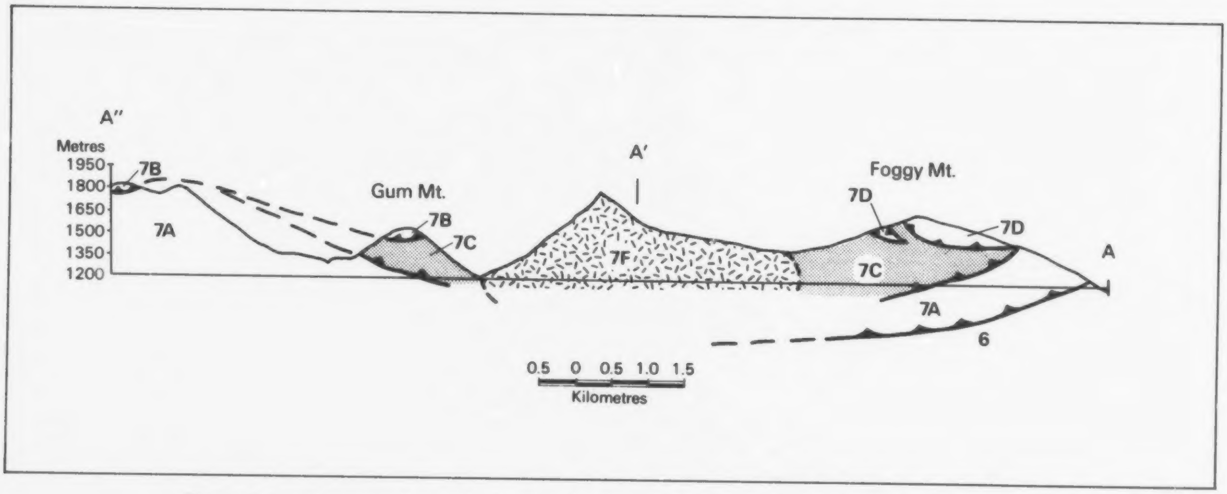


Figure 3-6-4. Cross-section A-A'-A" of Sylvester Allochthon from Big Creek to Gum Mountain.

Subdivision is based on: recurring distinctive lithologies, for example, salmon pink chert interbedded with sea green argillite; lithologic suites, for example, subvolcanic massive andesite, flow breccias containing subvolcanic andesite clasts, and intercalated andesitic greywacke-siltstone; or similar geologic histories, for example, chert intruded by numerous basalt/diabase dykes. As shown in Table 3-6-1, the allochthon is dominated by "oceanic" lithologies: cherts, argillite, limestone; basalt flows and breccias; basalt/diabase dykes and sills; a coarse-grained gabbro that is strongly foliated to mylonitic in part, and locally intruded by diabase dykes; and extensive ultramafites. Subordinate "nonoceanic" lithologies include Unit 7E, a trachyandesite suite with derived sediments and subvolcanic equivalents; Unit 7F, a zoned hornblende gabbro to granodiorite complex that intrudes cherts; and minor terrigenous siliciclastic greywackes that contain detrital muscovite, tourmaline and zircon. Individual thrust-bounded slices of a single unit may be widely scattered. They range in size from sheets that compose entire mountains down to blocks a few metres in diameter that are enclosed in scaly serpentinite. This degree of dismemberment suggests large-scale boudinage.

The Sylvester Allochthon was assembled into its present form during two or more distinct episodes of telescoping. Late Paleozoic thrust imbrication has been documented by Harms (1986) in the Cry Lake map area and may be important elsewhere; this event is unrelated to the Sylvester-North America encounter. Internal telescoping of the allochthon accompanied its emplacement onto the North American continental margin during Jurassic time.

CASSIAR BATHOLITH (UNIT 8 — CRETACEOUS-EOCENE)

Intrusive rocks of the Cassiar batholith occupy the western border of 104O/16. Coarse-grained quartz monzonite, with pink orthoclase megacrysts, and coarse-grained biotite-hornblende grandiorite constitute 98 per cent of these exposures. The remainder are younger intrusive phases — medium-grained granites, particularly on the Ran claims and at the Lucky showing, and ubiquitous but narrow pegmatites and aplites. In the southwest corner of the area, northwest-trending mylonite zones cut megacrystic quartz monzonite and granodiorite, but not the younger medium-grained granite. Displacement indicators such as asymmetric pressure shadows and folded aplite dykes show right lateral and also east-side-up motion across these zones.

Mineralization within the Cassiar batholith includes gold-bearing porphyry type (Ran claims) and vein swarms [Nancy (MI 104O-013), Lucky, Luck (MI 104O-033) showings]. Economic minerals include molybdenite, gold with pyrite, argentiferous galena, and argentite.

STRUCTURE

Two regional structural events affected the rocks in 104O/16. The older event, the Early Jurassic collisional episode, involved major shortening of the North American continental margin and also emplacement of the Sylvester Allochthon. The younger event reflects Late Cretaceous-Early Tertiary wrench faulting. More than 90 per cent of the relative movement between the Sylvester Allochthon and North America must have been taken up along the Sylvester-Earn contact. The 10 metres or so across this contact are never exposed. Thin sandstone beds in the uppermost Earn have been disrupted and rotated. The remaining relative movement penetrated into the miogeoclinal pile where its effects coincide in style, geometry and timing with those of the overall crustal shortening process. Thin-bedded argillaceous units — Earn slates and the Kechika Group — were intensely strained, while thick, brittle units — primarily the McDame-Tapioca sandstone - moved as rigid blocks bounded above and below by décollements. Analogous duplex-style deformation has been documented further south in strata below the Sylvester Allochthon by Harms (1986). In 104O/16, a set of northeast-vergent thrust ramps developed in North American strata within the range between Weirami Mountain and Hamlet Mountain (Figure 3-6-2). These thrusts show characteristic "snake's head" morphology (Suppe, 1983) in cross-section (Figure 3-6-5) and die out over a short distance to the northeast. Thrust imbrication of the McDame Group may occur near the Berg showing.

South and west of the Ewen Barite occurrence (MI 104O-050), a northeast-vergent bedding-parallel thrust brings Earn strata over basal Sylvester cherts (Figure 3-6-2). This structure developed late in the deformational episode, after the Sylvester Allochthon was essentially in place.

Map-scale folds are scarce. The style of deformation — shortening concentrated within favourable stratigraphic horizons — did not favour development of major folds but minor structures are ubiquitous. One or more slaty or fracture cleavages are common. Minor structures include bedding-parallel cleavage in all slaty rocks, fine crenulations on slaty cleavages, minor to outcrop-scale folds, boudinage, rodding and pencil cleavage, clast elongation in conglomerates, and fibrous quartz growth around pyrite nodules.

TABLE 3-6-1
MAPPABLE LITHOTECTONIC UNITS WITHIN THE SYLVESTER ALLOCHTHON

Unit in Figure 3-6-2	Lithologic Subpackages	Description	Localities	Relationship to Other Lithologic Subpackages
7A: chert, argillite, limestone	1. grey, green, black chert, grey-black argillite	bedded chert with intercalated argillite; also black ribbon chert (less common). Probably embraces a considerable age span, probably internally imbricated. Minor andesite slivers, carbonate-altered "felsic" sills on Whitehorn Mtn.	widespread in 7A	
	2. limestone	impure limestone with lithic fragments; purer grey limestone. Small lenses in (1); occurs as a mappable unit only on Shambling Mtn.	Shambling Mtn.	with (1). Some at least is depositionally within the chert-argillite sequence; the unit on Shambling Mtn. may be a tectonic slice
	3. limestone extensively replaced by massive black chert	in places silicification is so extensive that the unit is a massive black chert with minor limestone blobs	Shambling Mtn. Whitehorn Mtn. Jousting Plateau Foggy Mtn.	in apparent depositional contact with chert-argillite
	4. salmon and green chert	salmon-coloured to tan to green chert with interbedded sea green argillite; minor rusty weathering limestone	east of Shambling Mtn. West of Canopener Lake Jousting Plateau Whitehorn Mtn.	intercalated in (1). On Jousting Plateau, apparent gradational contact. Elsewhere probably tectonic boundaries
	5. greywacke	slivers or interbeds within (1): not large enough to be mappable but significant genetically. Contain detrital muscovite, tourmaline, zircon		
7B: chert, argillite, basalt, diabase	1. chert-argillite with diabase and basalt sills and dykes	grey to green chert and argillite — includes green tuffs with chert fragments. Intruded by very fine-grained to aphanitic basic intrusive rocks that compose up to 75% of unit	Shambling Mtn. (top) North Foggy Mtn. Cypress Mtn. Whitehorn Mtn. (top) Sentinel Mtn. (SE ridge)	
	2. aphanitic basalt flows, pillowed flows, pillow breccia, dykes; local red ferruginous chert and green chert	apparently same igneous lithologies as (1) but extrusive material predominates. This unit contains areas of highly flattened breccias, with volcanic and chert clasts in ferruginous or green chert matrix	Sentinel Mtn. (top) Gum Mtn. Foggy Mtn. Hill west of Gum Mtn. (top)	

Unit in Figure 3-6-2	Lithologic Subpackages	Description	Localities	Relationship to Other Lithologic Subpackages
7C: serpentinite	1. serpentinite	parts are thoroughly tectonized — scaly, boudin-filled; other parts retain primary textures, bastites. Serpentinite masses contain blocks and slivers of other lithologies, e.g. gabbro blocks on Foggy Mtn.	Foggy Mtn. Gum Mtn. South Post Ridge Hill east of Hamlet Mtn.	
7D: Coarse-grained, in part foliated gabbro, locally brecciated and/or cut by dykes	1. gabbro	coarse-grained gabbro. Originally pyroxene-plagioclase gabbro. Has undergone extensive upper greenschist-lower amphibolite metamorphism. In places highly foliated to mylonitized	Foggy Mtn.	
	2. gabbro-dyke complex	foliated gabbro cut by extensive very fine-grained unfoliated mafic dykes	Foggy Mtn.	
	3. brecciated gabbro	foliated gabbro ± basalt clasts in very fine-grained dust-tuff matrix; on Gum Mtn. clasts of this lithology occur in limestone matrix	Foggy Mtn. Gum Mtn. Hill south of Canopener Lake	
7E: Trachyandesite flows, subvolcanic intrusives, pyroclastic-epiclastic sediments	1. Trachyandesite flows and coarse pyroclastic material are predominant.		South Post Ridge Hill south of Foggy Mtn.	All of these units occur in a gradational sequence with a centre marked by predominance of subvolcanic lithologies at the east end of South Post Ridge.
	2. Subvolcanic porphyritic intrusions are predominant.			
	3. Epiclastic sediments (greywacke-volcanic siltstone) are predominant.			
7F: Zoned hornblende gabbro-tonalite-granodiorite complex			Mtn. east of Gum Mtn.	cut by "andesite" dykes similar to the trachyandesites of 7E. May be basement to 7E

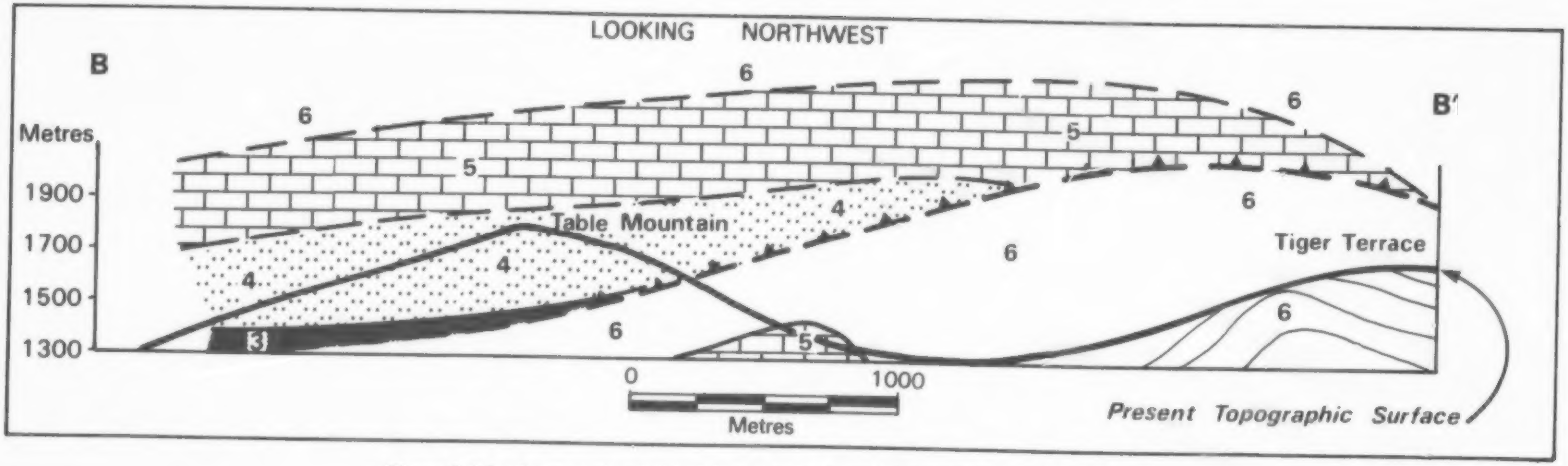

LOOKING NORTHWEST
B
B'
Metres
1900
1700
1500
1300
6
6
6
6
6
6
6
5
5
5
4
4
4
3
Table Mountain
Tiger Terrace
0
1000
Metres
Present Topographic Surface

Figure 3-6-5. Cross-section B-B' of thrust ramps in autochthonous strata, Table Mountain.

Minor structures in autochthonous and allochthonous rocks coincide geometrically. In most of the area fold axes and linear structures trend northwest and plunge gently northwest and southeast.

The overall Jurassic episode involved several superimposed generations of folding and cleavage. In a given outcrop, isoclinal folds may be succeeded by coaxial but upright folds; or two sets of crenulations diverging by 15 to 20 degrees may deform the same bedding-parallel cleavage. Bedding-parallel cleavage is always the earliest planar structure. It is succeeded in some outcrops by a steep southwest-dipping cleavage and in others by one that dips to the northeast.

Atan and Kechika rocks next to the Cassiar batholith define a separate structural domain, identified by steep (30 to 60-degree) plunges of fold axes. High-angle faults separate this domain from the rest of the map area and commonly juxtapose disparate stratigraphic units within it.

The second major deformation is expressed as swarms of high-angle faults that equally offset both autochthonous and Sylvester rocks. One concentration of faults occupies the Tootsee River valley, with a major horsetail around the Midway deposit. A second set of faults is located east of the Ewen Barite. These two fault systems form part of a regional pattern that links the northern end of the Kechika fault to the Cassiar fault. The overall fault pattern probably developed in order to transfer motion and accommodate strains between these two major dextral transcurrent faults. Timing of the motion is poorly constrained, but some strands of the Tootsee River system apparently predate the Cassiar batholith.

Late minor east to northeast-trending structures include chevron and kink folds, *en échelon* extension gashes and dilatant quartz veins. They concentrate in Earn and Sylvester rocks in the northwestern part of the map area. They probably developed in response to movement on the Tootsee River fault system.

MINERALIZATION AND MINERAL OCCURRENCES

Three major episodes of mineralization can be identified in 104O/16, Upper Devonian-Lower Mississippian, mid-Cretaceous and Late Cretaceous-Eocene. Each episode produced a distinctive type or types of mineral deposit (Table 3-6-2).

(1) **Upper Devonian-Lower Mississippian** — The Earn Group hosts baritic exhalites, such as Perry and Ewen Barite; and siliceous exhalites in the Midway area and south to Tiger Terrace, which contain pyrite and to a lesser extent sphalerite and traces of galena. These deposits fit the sedex model (Carne and Cathro, 1982).

(2) **Mid-Cretaceous** — Mineralization associated with the main phase of the Cassiar batholith includes: molybdenite in quartz veins and scheelite in adjacent skarns at the Nancy showing; and silver-lead-zinc replacement lenses and veins at the Amy occurrence. Greisenized, tourmaline-bearing granite from the Amy area has been submitted for potassium-argon dating.

(3) **Late Cretaceous-Eocene** — Mineralization that postdates the main phase of the Cassiar batholith is associated with late intrusive phases, such as medium-grained granite or porphyritic rhyolite dykes, and/or with zones of strong sericite alteration. The nature of the mineralization varies dramatically, depending on the host rock. Massive carbonate units host manto-type deposits: Midway in the McDame Group, Silverknife and Butler Mountain (southern Yukon) in the Rosella Formation. The Cassiar batholith hosts silver-lead-zinc veins, such as the Lucky and Luck, and porphyry-type mineralization within and south of the Ran claims where quartz veins within an extensive sericite alteration zone carry sporadic molybdenite and gold and silver values.

The Tootsee River fault system exerted structural control over the location of several important deposits: Midway (MI 104O-047), Silverknife and Butler Mountain fall within it. Midway lies at the intersection of a linear defined by a series of west-northwesterly trending sericite alteration zones (Gum Mountain-Pyrrhotite Creek, Brinco Hill) and the Tootsee River fault system. These alteration zones contain quartz stockworks, abundant secondary pyrite and minor silver-lead-zinc in veins, seen in float at base of Gum Mountain. The Tootsee Star vein showing (MI 104O-039) may also be related to this system. Porphyritic rhyolite dykes occur on Gum Mountain and at the base of Pyrrhotite Creek.

TABLE 3-6-2
MINERAL OCCURRENCES, 104O/16

	Name	Minfile No.	Economic Minerals	Description
I. Upper Devonian-Lower Mississippian Sedex type, in Earn Group	1. Midway exhalites — Discovery Zone, Upper Zone, etc.	104O-038	sl, gn? py	bedded siliceous pyritic exhalites; in some cases with minor barite, sphalerite, galena. in fine-grained Earn clastics
	2. Ewen Barite	104O-050	barite	pure, bedded barite exhalite in fine-grained Earn clastics
	3. Perry Barite		barite	pure, bedded barite exhalite in fine-grained Earn clastics; more or less on strike with Ewen Barite, forms a synclinal keel cut off above by a shallowly dipping thrust/decollement
II. Deposits related to main phase of Cassiar batholith (probably mid-Cretaceous)	4. Nancy	104O-013	mb, gn, sl, scheelite, py	molybdenite, plus minor pyrite, galena, sphalerite in quartz veins cutting coarse-grained granite; scheelite in adjacent skarns in Kechika Group rocks

	Name	Minfile No.	Economic Minerals	Description
II. Deposits related to main phase of Cassiar batholith (probably mid-Cretaceous)	5. Amy	104O-004	sl, gn, aspy, freibergite, py	concordant lead-zinc-silver replacement zones in limy Kechika Group sediments adjacent to Cassiar batholith. The Kechika sequence is cut by several coarse-grained muscovitic, greisenized late stage dykes of Cassiar batholith
III. Deposits of Late Cretaceous to Eocene age A. Manto Lead-Zinc Silver	6. Midway — Lower Zones Discovery and Silver Creek Deposits	104O-047	gn, sl, aspy, py, po, marcasite, cpy freibergite, pyrargyrite, geocronite, cassiterite	irregular replacement Ag-bearing massive sulphide bodies at or near top of McDame Group
	7. Silverknife	104O-048	gn, sl, pyrargyrite, tetrahedrite, py	sulphide replacement zones, generally concordant, in marble at gradational Atan-Kechika contact. Hornfelsing is pervasive although source not exposed. No surface showings. Strike length reported 137 m, true width 4.6 m. Weighted average assay values to 511 g/tonne Ag, 3.7 g/tonne Au, 12.25% Pb, 4.8% Zn
B. Lead-Zinc-Silver Veins	8. Tootsee Star	104O-039	gn, sl, py	quartz veinlets in narrow shear zone hosted by Sylvester argillites-cherts. A grab sample assayed 35.3 g/tonne Ag
	9. Lucky		gn, sl, tet?	Two northeast-trending veins, marked by boulder trains on B.C. side of border, cut medium-grained granite and megacrystic (main phase Cassiar) granite
	10. Luck	104O-033	gn, sl, cpy	one out of the five veins in this occurrence is located on the B.C. side of the border. They all trend roughly east-west and cut Cassiar granite
	11. Silvertip	104O-003	gn, sl, tetrahedrite, stannite, py	lead-zinc-silver replacement bodies in McDame limestone; surface exposures highly oxidized. Presence of tin indicates magmatic hydrothermal source
	12. Ran, Reb, Hat claims	104O-037	py, mb, argentite, gn, sl, cpy	Extensive sericite alteration zone in Cassiar batholith; fine-grained granite, rhyolite dykes. Mineralization in quartz veins: Au to 0.7 g/tonne on Reb claims (A.R. 9128), Ag to 3800 g/tonne on Ran claims (grab sample this program).
IV. Other	13. Berg	104O-015	gn, sl, py, hydrozincite, cerussite	highly oxidized mineralization, mostly chunks of Fe-Mn gossan, occurs where a thin screen of Earn sediments overlie McDame limestone
	14. Gunnar Berg	104O-032	gn, mb, scheelite	quartz breccia zone in Tapioca sandstone quartzite adjacent to altered, quartz veined Cassiar contact. Mineralization is minor

Exploration for manto deposits of the Midway type should focus on the following three parameters:

(1) Massive carbonate host rocks. Although Midway is localized within the McDame Group, where early karsting played a role in ground preparation, the Cambrian Rosella Formation also hosts manto mineralization and should not be overlooked.

(2) Proximity to major normal fault systems. The Tootsee River fault system extends 15 kilometres north of the Yukon border, where it intersects a segment of the Kechika fault. The fault system east of the Ewen Barite deposit and its northward extension into the Yukon are also favourable structural targets.

(3) Association with sericite alteration and felsic dykes. The magmatic hydrothermal systems that give rise to manto mineralization in massive carbonates tend to produce an "epithermal" imprint in noncarbonate rocks.

CONCLUSIONS

Map area 104O/16 is underlain in part by autochthonous miogeoclinal strata ranging from Lower Cambrian to Lower Mississippian. The youngest autochthonous stratigraphic unit, the Earn Group, hosts baritic and siliceous exhalites analogous to sedex deposits east of the Tintina fault. The Sylvester Allochthon overrode the North American continental margin in Jurassic time as part of a collisional event that produced a wide variety of major and minor structures, including northeasterly verging thrusts that involve miogeoclinal rocks.

Late Cretaceous to Eocene major high-angle wrench fault systems in 104O/16 developed in response to larger scale dextral movement on the Kechika and Cassiar faults.

Manto silver-lead-zinc deposits postdate the main, mid-Cretaceous phase of the Cassiar batholith. They are controlled by the coincidence of favourable massive carbonate host rocks (McDame or Atan), major high-angle faults, volumetrically insignificant amounts of felsic intrusive rocks and, in the case of Midway, are spatially associated with strong sericite alteration in noncarbonate lithologies.

ACKNOWLEDGMENTS

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STRATIGRAPHY AND TECTONICS OF THE GATAGA AREA NORTHEASTERN BRITISH COLUMBIA*
(94E/16, 94F/14, 94K/4, 94L/1, 94L/7, 94L/8)

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INTRODUCTION

This paper presents the results of two field seasons regional and detailed mapping of the Gataga area of northeastern British Columbia (Figure 3-7-1), within NTS sheets 94E/16, 94F/14, 94K/4, 94L/1, 94L/7 and 94L/8. The research described forms part of a multidisciplinary study of the tectonics, sedimentation and mineralization of the middle to late Paleozoic Kechika trough.

The Gataga area contains major stratiform barite-zinc-lead mineralization, for example, the Driftpile Creek, Bear and Saint occurrences (McClay and Insley, 1986; MacIntyre, 1981, 1983; Carne and Cathro, 1982). The objectives of the research program are: to determine the stratigraphy and structure of the Gataga area; to determine the nature and extent of the stratiform mineralization; to investigate the mineralogy and geochemistry of the mineral deposits; and to develop models for their deposition and distribution. In the 1986 field season detailed structural and stratigraphic mapping was carried out at a scale of 1:20 000 over approximately 3000 square kilometres of the Gataga area (Figure 3-7-1).

Previous work in the Gataga area has chiefly been reconnaissance style 1:250 000-scale mapping (Gabrielse, 1962; Taylor and Stott, 1973; MacIntyre, 1981, 1983) and detailed exploration of the Driftpile and Bear mineralization by Archer Cathro & Associates on behalf of the Gataga Joint Venture (Carne and Cathro, 1982). This project began in 1985 with detailed mapping of the Driftpile Creek area (McClay and Insley, 1986) and continued in 1986 with a regional mapping program designed to investigate the tectonics and stratigraphy of the Gataga district. Strata range from Late Precambrian (Hadrynian) to Mississippian in age and occur in a 180-kilometre-long, northwest-trending complex fold and thrust belt within the western Rocky Mountains. The stratiform barite-iron-zinc-lead mineralization occurs in Devonian siliciclastic rocks of the Kechika trough, the southern extension of the Selwyn Basin in the Yukon.

LOCATION AND TOPOGRAPHY

The Gataga area lies within the Muskwa Range of the northern Rocky Mountains, between the Kechika River (the northern extension of the Rocky Mountain Trench) to the west, the Gataga River to the east and northeast and Weissener Creek to the south. Elevations range from 1100 metres to over 2500 metres, and the area is characterized by long ridges and valleys parallel to the dominant northwest-trending structural grain. Treeline reaches up to the 1500-metre elevation with abundant vegetation of mixed woodland in valley bottoms and poplar, pine and grasses on higher ground. The best outcrop is found in river sections and at the higher elevations. Access to the area was by helicopter from Sturdee Valley (in the Toodoggone area) or fixed-wing aircraft from Dease Lake. A 640-metre dirt airstrip, approximately 2 kilometres from the base camp on Driftpile Creek (latitude 58°04′ north; longitude 125°55′ west), at an elevation of 1340 metres, is suitable for small fixed-wing aircraft.

GEOLOGICAL SETTING OF THE GATAGA AREA

The Gataga fold and thrust belt includes part of the northwest-trending Kechika trough, the southern extension of the Paleozoic Selwyn Basin (Figure 3-7-1). It is bounded on the west by the Rocky Mountain Trench-Kechika dextral strike-slip fault system (Gabrielse, 1985) and on the east by folded and thrusted Hadrynian siliciclastics (Taylor and Stott, 1973) (Figure 3-7-2). Strata within the Gataga area include: Hadrynian through Late Cambrian platformal siliciclastics and carbonates; Cambro-Ordovician through Silurian fine-grained siliciclastics, carbonates and cherts; mid-Devonian to Mississippian fine-grained, black siliciclastics of the Kechika trough. The Gataga fold and thrust belt comprises four distinct tectono-stratigraphic assemblages bounded by steeply southwesterly dipping thrust faults verging to the northeast (Figure 3-7-2). Within each thrust slice the strata generally young westwards. In addition to the stratiform sulphide deposits of the Gataga area, the Kechika trough also hosts the Cirque, Elf and Fluke barite-zinc-lead deposits (MacIntyre, 1983) further to the south (Figure 3-7-1). These deposits are considered to have formed from metalliferous fluids discharged into local basins along contemporaneous block faults related to crustal extension during the Middle to Late Devonian (Gordey *et al.*, 1982; MacIntyre, 1983).

STRATIGRAPHY

Stratigraphic nomenclature adopted in this report follows that of Fritz (1980), Gabrielse (1962), MacIntyre (1983) and Taylor and Stott (1973). Strata range in age from Hadrynian through to early Mississippian and form a complex northwest-striking fold and thrust belt. Generally recessive Ordovician through Devonian shales, siltstones, cherts, thin limestones and lensoidal bodies of chert pebble conglomerate form a highly deformed core in the eastern part of the thrust belt, centred about the Driftpile Creek

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

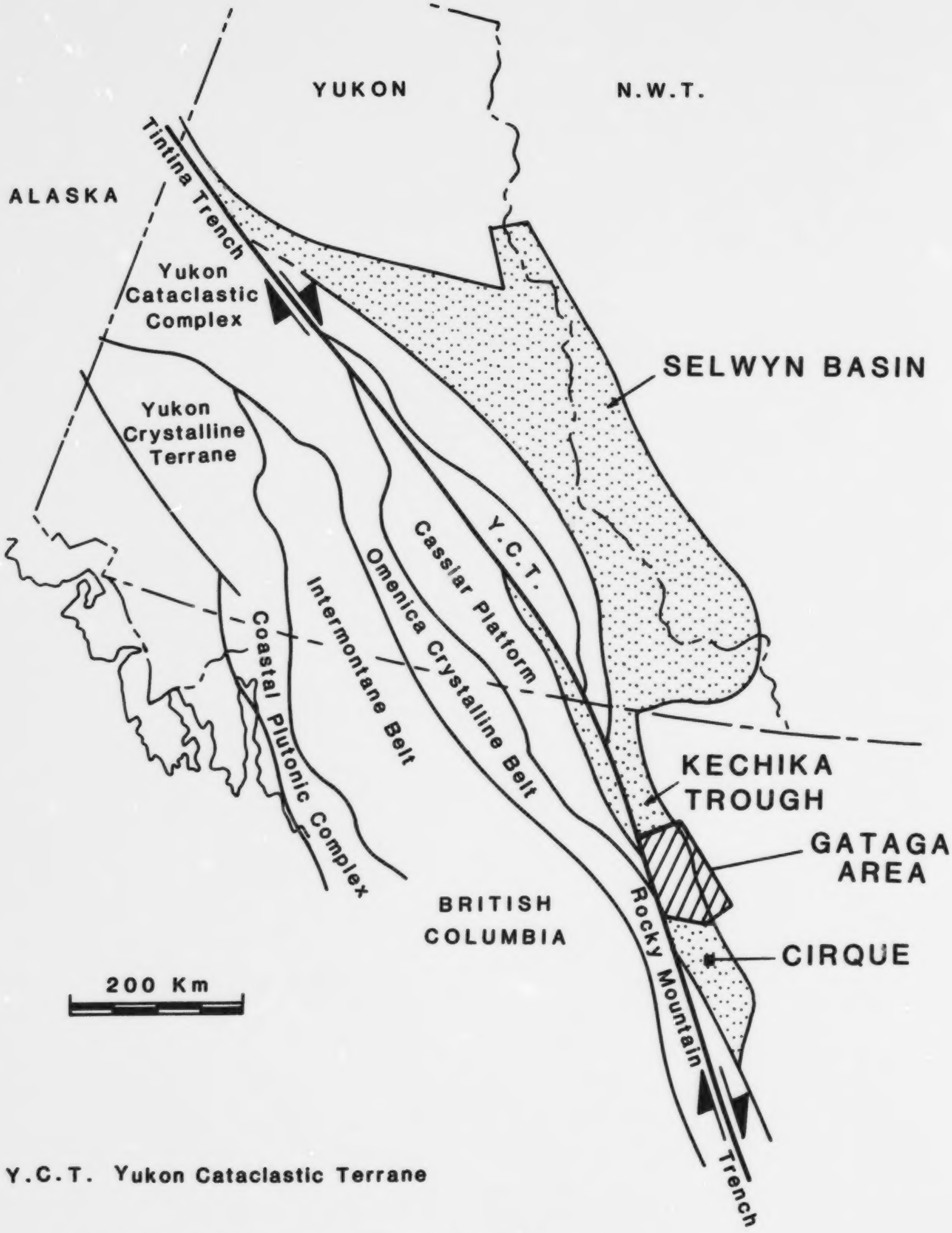
YUKON
N.W.T.
ALASKA
Tintina Trench
Yukon Cataclastic Complex
SELWYN BASIN
Yukon Crystalline Terrane
Y.C.T.
Cassiar Platform
Omenica Crystalline Belt
Intermontane Belt
Coastal Plutonic Complex
KECHIKA TROUGH
GATAGA AREA
BRITISH COLUMBIA
Rocky Mountain Trench
CIRQUE
200 Km
Y.C.T. Yukon Cataclastic Terrane

Figure 3-7-1. Regional setting of the Gataga area in the Kechika trough of Northeastern British Columbia.

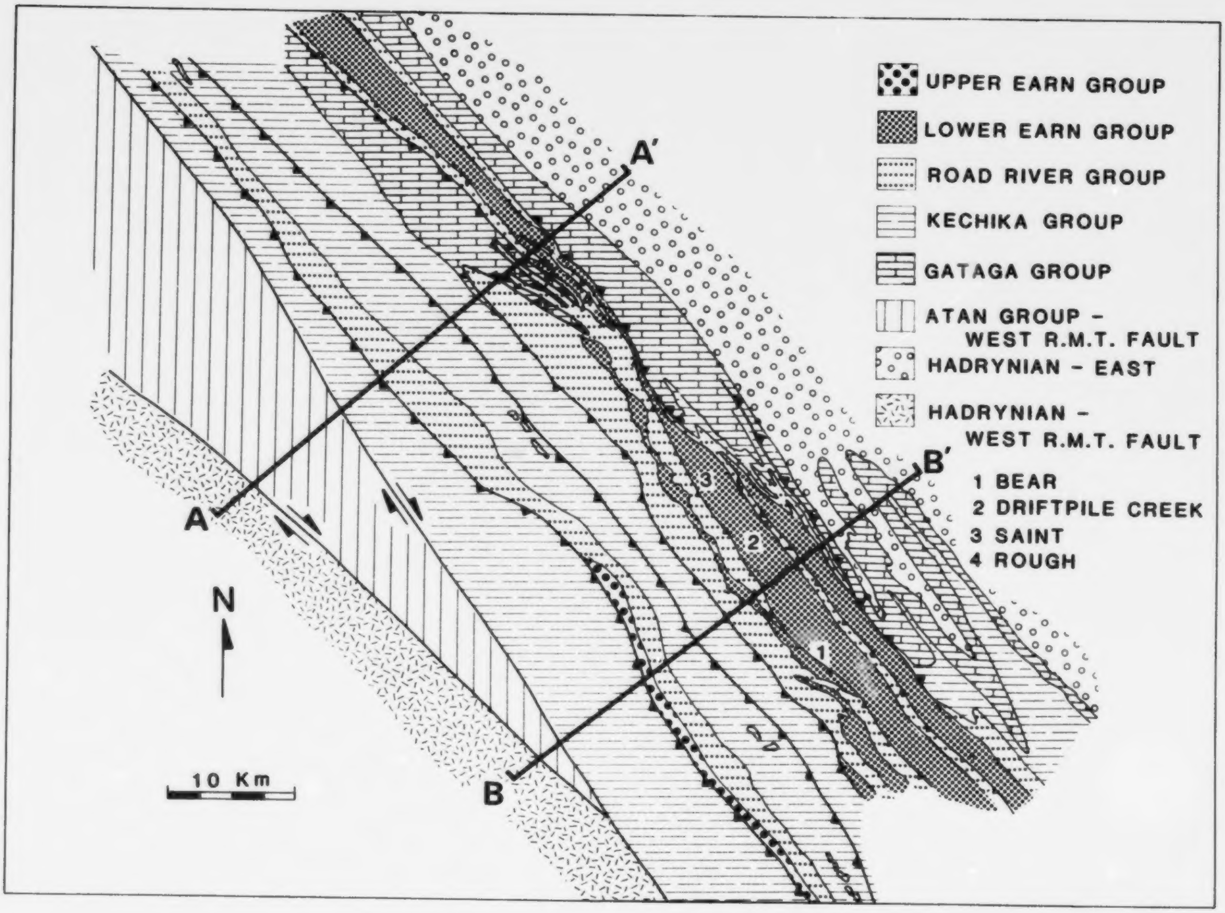

Figure 3-7-2. Summary geological map of the Gataga area.

deposit (Figure 3-7-2). These siliciclastic rocks are flanked to the west by more resistant, west-dipping thrust panels of strongly folded Cambrian through early Ordovician limestones, dolomites, dolomitic siltstones and phyllites of the Kechika Group (Figure 3-7-3). Thick, strongly resistant, steeply dipping panels of folded and thrust Proterozoic argillites and sandstones together with Cambrian quartzites and limestones form the eastern margin of the Gataga area. Stratigraphic columns incorporating data from both the eastern and western parts of the area are shown in Figure 3-7-3. In places accurate thickness determinations are hampered by the intense deformation and cleavage development.

LATE PROTEROZOIC (HADRYNIAN) — EASTERN PART OF THE MAP AREA

The lowermost strata exposed in the map area are a thick succession of green slates, phyllites, brown sandstones, quartz pebble grits and minor oolitic limestone lenses. These lithologies are interpreted to be Late Proterozoic (Hadrynian) in age (Taylor and Stott, 1973), and form the cores of anticlines and the hangingwall panels of thrust sheets at the eastern margin of the map (Figure 3-7-2). They are generally poorly exposed and strongly deformed with penetrative cleavages found in the phyllitic units.

LATE PROTEROZOIC (HADRYNIAN) — WESTERN PART OF THE MAP AREA

West of the Rocky Mountain Trench dextral strike-slip fault (Figure 3-7-2) strongly deformed metaquartzites and schists of the Late Proterozoic Swannell Formation (Evanchick, 1985) form the resistant outcrops of the Sifton Ranges. The quartzites are in places strongly sheared and recrystallized and have reached garnet-grade upper greenschist facies metamorphism. These units were not mapped in detail.

GATAGA GROUP (CAMBRIAN) — EASTERN PART OF THE MAP AREA

The Gataga Group (informal name) comprises a thick (1.1 to 2.0 kilometres) miogeoclinal succession of shallow water clastic sediments and carbonates that form the eastern outcrops of the fold and thrust belt (Figure 3-7-4). The Gataga Group comprises six mappable members — three clastic units and three carbonate units (Figure 3-7-3), most of which can be traced throughout the map area.

The lowermost member, the Lower Clastic unit, consists of 100 to 150 metres of thin to medium-bedded quartzites and phyllitic siltstones that conformably overlie the Late Proterozoic phyllite suc-

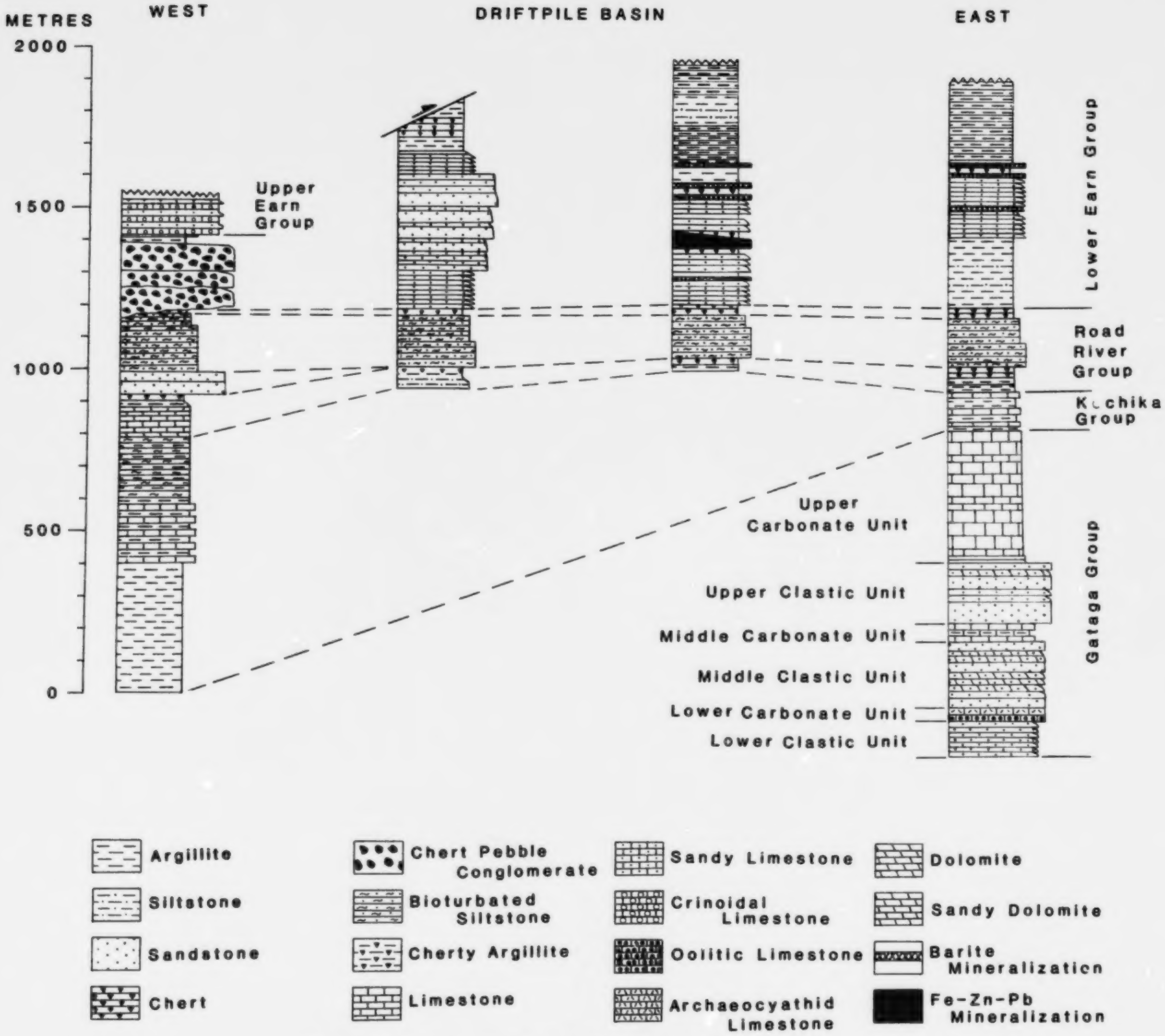
METRES
WEST
DRIFTPILE BASIN
EAST
2000
1500
1000
500
0
Upper Earn Group
Lower Earn Group
Road River Group
Kechika Group
Gataga Group
Upper Carbonate Unit
Upper Clastic Unit
Middle Carbonate Unit
Middle Clastic Unit
Lower Carbonate Unit
Lower Clastic Unit
Argillite
Siltstone
Sandstone
Chert
Chert Pebble Conglomerate
Bioturbated Siltstone
Cherty Argillite
Limestone
Sandy Limestone
Crinoidal Limestone
Oolitic Limestone
Archaeocyathid Limestone
Dolomite
Sandy Dolomite
Barite Mineralization
Fe-Zn-Pb Mineralization

Figure 3-7-3. Summary stratigraphic columns for the Gataga area.

cession. It is overlain by a distinctive 20 to 60-metre-thick Lower Carbonate unit that consists of medium to thick-bedded, grey oolitic and Archaeocyathid limestones. These limestones are in turn overlain by approximately 200 metres of medium to thick-bedded white quartzites and buff-weathering dolomitic grits and sandstones. These lithologies typically exhibit well-developed tabular and trough crossbedding. The quartzite beds contain abundant well-developed *skolithos* trace fossils.

The Middle Carbonate unit comprises 60 metres of distinctively purple-grey-weathering, medium-bedded limestones with interbedded calcareous and noncalcareous shales. This forms a regional marker unit in most of the map area. The Middle Carbonate unit is followed by approximately 200 metres of thick-bedded white orthoquartzites and buff-weathering dolomitic grits and sandstones — the Upper Clastic unit. In places the orthoquartzite beds contain abundant *skolithos*. The Upper Clastic unit grades upwards into a distinctive medium to thin-bedded, buff-weathering fenestral dolomite that is overlain by medium to massively bedded grey, fine-grained micritic, oolitic and algal laminated limestones. These shallow water limestones and dolomites of the Upper Carbonate unit are in places approximately 1 kilometre thick and form very resistant and rugged outcrops in the eastern and northern parts of the area.

Fritz (1980) measured sections from the Upper Carbonate to within the Middle Clastic unit and assigned the latter to the late Lower Cambrian *Bonnia-Olenellus* zone based upon trilobites recovered from the overlying Middle Carbonate.

In the northern part of the Gataga area the Middle Clastics, Middle Carbonates and Upper Clastics rapidly thin out whereas the Upper Carbonate may increase in thickness.

ATAN GROUP (CAMBRIAN) — WESTERN PART OF THE MAP AREA

West of the Rocky Mountain Trench strike-slip fault (Figure 3-7-4) a fault-bounded panel of Atan Group strata crops out. These rocks comprise thick units of folded and faulted carbonates and quartzites (Gabrielse, 1962; Mansy and Gabrielse, 1978) but were not mapped in detail during the course of this study.

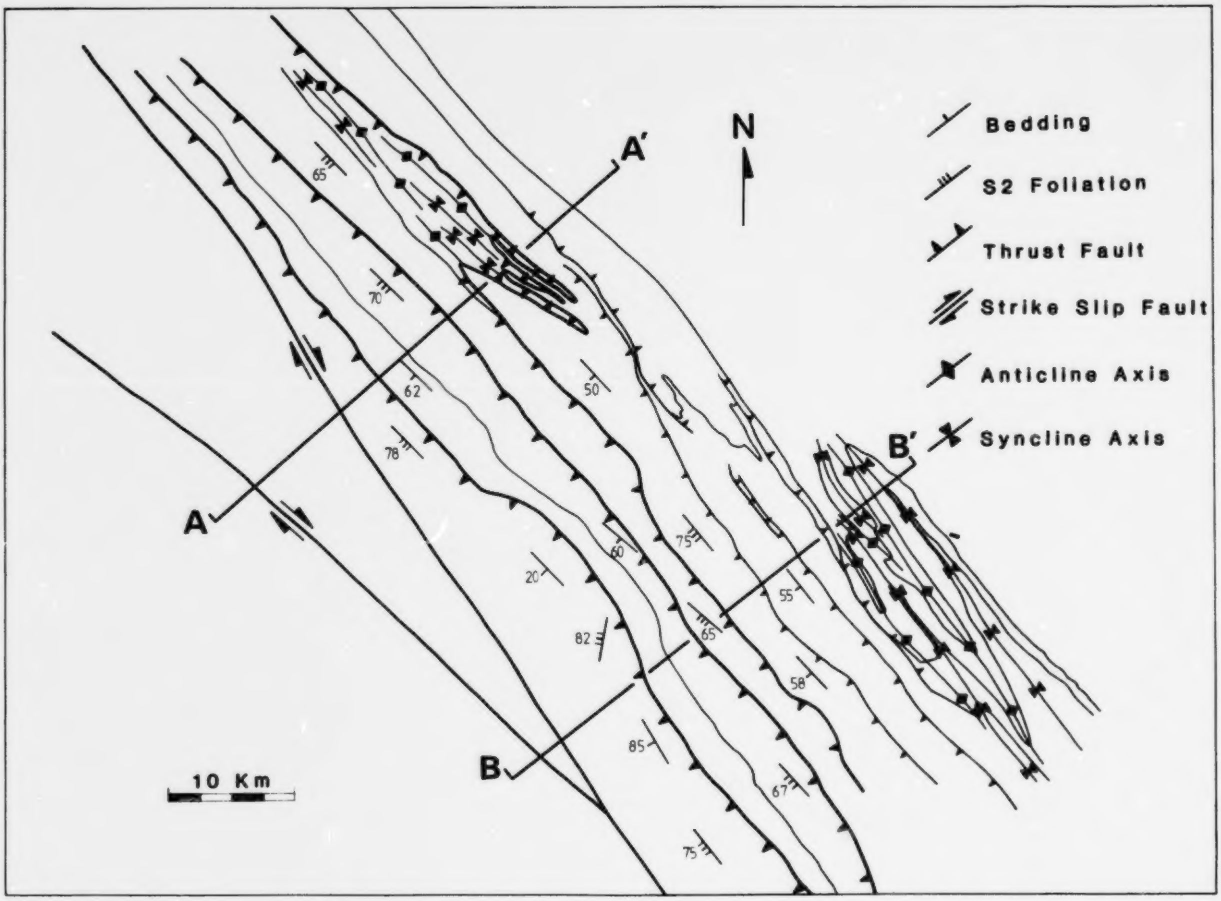

Figure 3-7-4. Tectonic sketch map of the Gataga area.

KECHIKA GROUP (UPPER CAMBRIAN-ORDOVICIAN)

The Kechika Group rocks appear to conformably overlie the Gataga carbonates in the eastern part of the map area. Here the Kechika Group consists of approximately 150 metres of grey-brown-weathering calcareous phyllites with intercalated thin-bedded limestones and is apparently conformably or paraconformably overlain by Ordovician black argillites and cherts.

In the western part of the map area the Kechika Group occurs in three major thrust panels (Figure 3-7-2). Within these thrust sheets the thin-bedded phyllites and calcareous phyllites of the Kechika Group are highly deformed, making estimation of their true stratigraphic thicknesses extremely difficult. A minimum of 400 metres of poorly laminated grey-blue phyllites passes upward into grey-brown phyllites with intercalated medium-bedded grey limestones. In this part of the map area the intercalated limestone beds are more abundant and generally thicker than in the east. The calcareous phyllites and limestones are in turn overlain by 200 metres of bioturbated whispy argillites containing *zoophycos* and irregular burrow trace fossils; rare trilobite fragments have also been found in this part of the section. This upper unit of the Kechika Group is characterized by distinctive orange-weathering ferroan dolomitic beds up to 12 metres thick.

ROAD RIVER GROUP (ORDOVICIAN TO LOWER DEVONIAN)

Ordovician through Lower Devonian Road River rocks conformably overlie the Kechika Group. In the Gataga area the basal Road River rocks are a thin (approximately 30 to 60 metres thick) succession of recessive, graptolitic carbonaceous black argillites, cherts and minor thin limestones. In the eastern and central parts of the area these units are overlain by 130 to 170 metres of resistant, distinctive orange-weathering dolomitic micaceous siltstones (Figure 3-7-3) containing Silurian graptolites and abundant burrow and grazing trail trace fossils. This Silurian siltstone is a distinctive map unit in the Gataga area; it is overlain by recessive, silver-grey-weathering black argillites, black cherts and minor limestones of early Devonian age. In the western part of the area (Figure 3-7-2) the thin-bedded Ordovician limestones are succeeded by 70 metres of thick-bedded brown-weathering quartzites with thin chert pebble grit beds at the base. These resistant quartzites are overlain by at least 180 metres of thin-bedded laminated to intensely bioturbated dolomitic siltstones of similar facies to that found in the eastern part of the map area. The intense deformation in the fine-grained siliciclastics of the basal sections of the Road River Group make thickness determinations and stratigraphic correlations difficult.

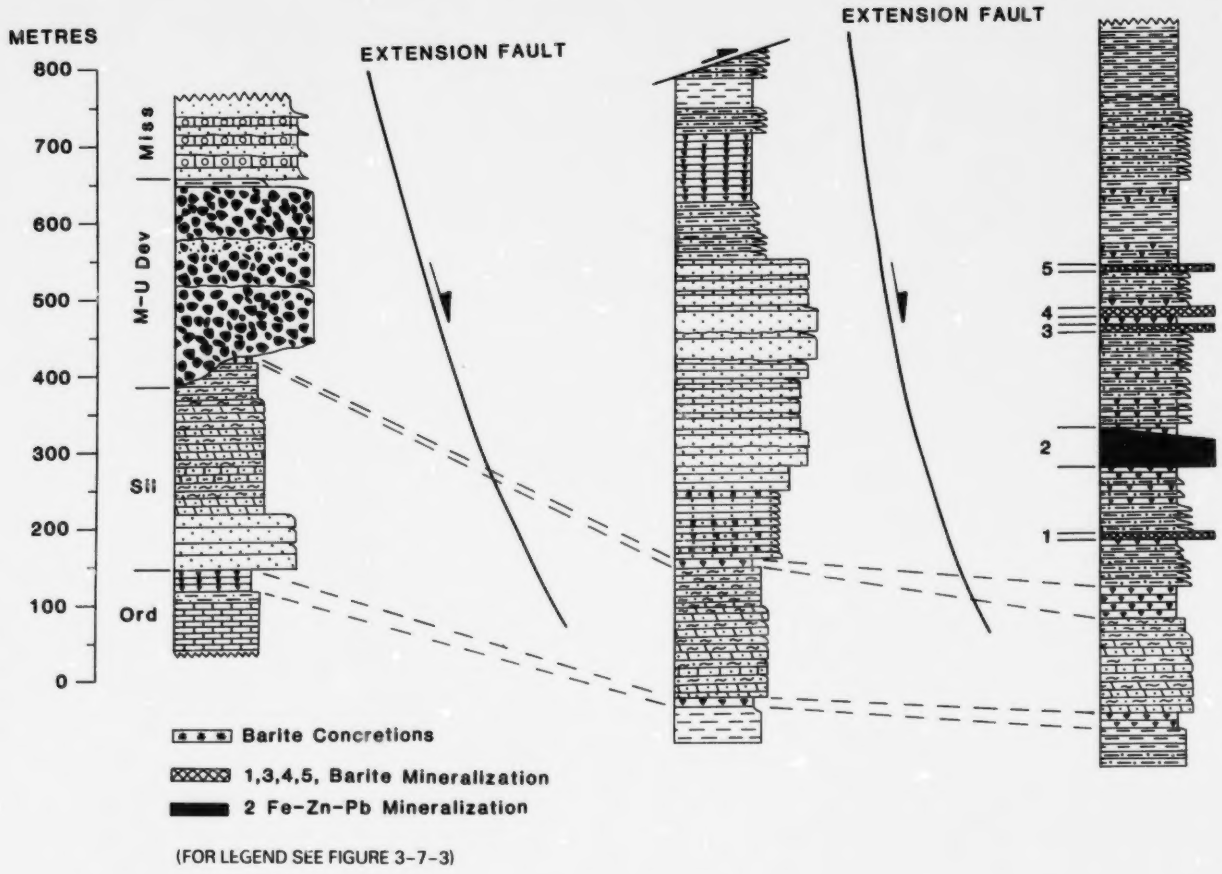

Figure 3-7-5. Detailed stratigraphic column of Devonian-Mississippian strata of the Gataga area.

LOWER EARN GROUP (MIDDLE TO LATE DEVONIAN)

The Road River Group is succeeded by a highly deformed sequence of Lower Earn Group (*sensu lato* after Gordey *et al.*, 1982) "black clastics". In the western part of the map area (Figure 3-7-2) the base of the Lower Earn Group is characterized by sheets and lenses of resistant thick-bedded chert pebble conglomerates and chert grits which interfinger eastwards with thin-bedded laminated siltstones and silt-banded argillites. The westernmost exposures of the Lower Earn Group are overlain by only a few tens of metres of fine-grained black argillites which are in turn overlain by the medium to thick-bedded crinoidal grainstones and sandstones of the Upper Earn Group.

In the eastern part of the map area the base of the Lower Earn Group is generally characterized by medium to thin-bedded chert-pebble grits and sandstones and local chert-pebble conglomerates. The conglomerates and grits are overlain by several hundred metres of recessive, unlaminated to thinly laminated silver-grey-weathering black argillites, cherty argillites and cherts which range in age from Frasnian to Fammenian (Orchard, personal communication, 1985). In the eastern part of the map area this late Devonian unit, informally called the Gunsteel Formation further to the south at the Cirque deposit (Jefferson *et al.*, 1983), contains stratiform barite-lead-zinc mineralization on at least three horizons and probably a further two horizons of stratiform barite mineralization (Figure 3-7-5). These horizons have been traced for 50 kilometres along strike and are complexly repeated by folding and thrust faulting.

UPPER EARN GROUP? (MISSISSIPPIAN)

This is the uppermost formation exposed in the map area and consists of a minimum of 70 metres of grey to black, medium to thick-bedded crinoidal grainstones, sandstones and siltstones with abundant shell debris which yield a Mississippian fauna (Gabrielse, personal communication, 1986). This unit is only found in the footwall of the westernmost major thrust fault in the map area (Figures 3-7-2 and 3-7-4) and the top of the unit is not preserved.

TECTONICS OF THE GATAGA AREA

The map area comprises four principal and distinct tectonostratigraphic packages which exhibit complex polyphase folding and thrust faulting (Figures 3-7-2 and 3-7-4).

Detailed structural analysis has indicated three deformation phases (McClay and Insley, 1986):

(1) An early cleavage phase of folding on northeast-trending axes. A local early cleavage is found around Phase 1 fold hinges.
(2) Dominant northwest-striking, northeasterly verging folding and thrusting with the accompanying development of a penetrative cleavage. The folds are tight to chevron style and generally plunge gently either to the northwest or to the southeast. All thrust faults are now steeply dipping and have been rotated into their steep attitude by movement on underlying thrusts.
(3) Late southwest to west-striking dextral reverse kink folding has produced minor folds, dilatant vein systems and minor reorientation of earlier structures.

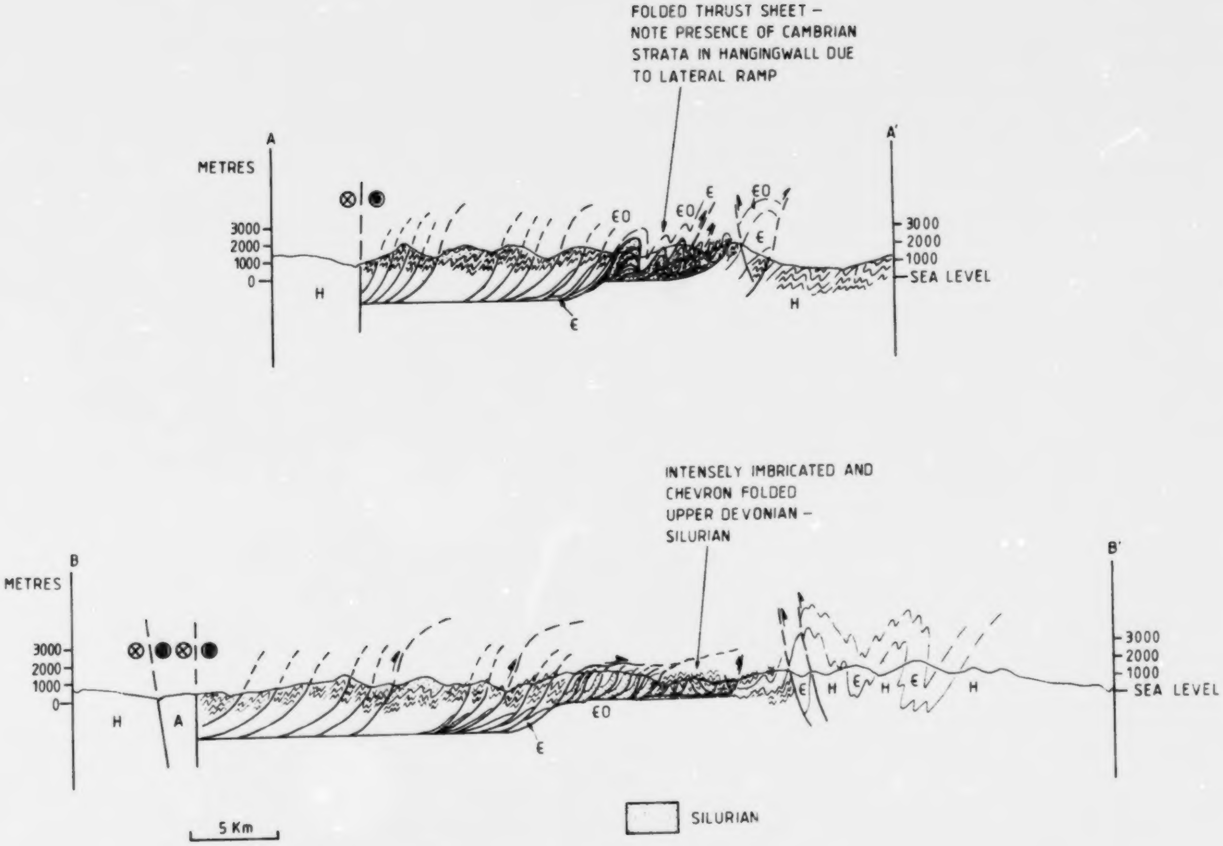
FOLDED THRUST SHEET – NOTE PRESENCE OF CAMBRIAN STRATA IN HANGINGWALL DUE TO LATERAL RAMP
A
A'
METRES
3000
2000
1000
0
SEA LEVEL
H
Є
ЄO
INTENSELY IMBRICATED AND CHEVRON FOLDED UPPER DEVONIAN – SILURIAN
B
B'
A
5 Km
SILURIAN

Figure 3-7-6. Cross-sections through the Gataga area.

In the western part of the map area the folds and thrusts show a northeasterly transport direction (that is, vergence northeast) whereas at the eastern boundary both northeast and southwest-verging folds and thrust faults are present. In the northern part of the area a large sheet of Cambrian strata has been thrust northeastwards over the recessive Ordovician through Devonian siliciclastics. Subsequent to emplacement this thrust sheet was folded by movement on underlying thrusts, giving rise to the complex map patterns in the northern part of the Gataga area (Figures 3-7-2 and 3-7-4).

MINERALIZATION

The Lower Earn Group siliciclastics of the Gataga area contain three to five intervals of stratiform barite (± zinc-lead) mineralization that can be mapped semicontinuously over a strike length of 50 kilometres (Figure 3-7-2). Within this mineralized interval (Figure 3-7-5) local lenses of sulphide enrichment have been the targets of exploration. Three occurrences of stratiform barite (± lead-zinc) mineralization have so far been identified, the Driftpile, Bear and Saint prospects (Figure 3-7-2). The most important is the Driftpile Creek deposit held by the Gataga Joint Venture. It consists of at least three stratiform intervals of barite-pyrite-galena-sphalerite mineralization. Preliminary biostratigraphic analysis using conodonts indicates a Frasnian to Fammenian (Late Devonian) age (M. Orchard, personal communication, 1985) for the deposits.

The barite mineralization is typically rhythmically interbedded massive, laminated and blebby barite and siliceous, cherty argillites over thicknesses from 5 to 50 metres. Detailed descriptions of the mineralization are given in McClay and Insley (1986).

In the northern part of the Gataga area the Rough prospect is an occurrence of vein-style mineralization (quartz, pyrite, ± galena and sphalerite) in cherty argillites, chert breccias and dolomitic siltstones. The mineralization can be traced over a strike length of 5 kilometres and occurs in the immediate footwall of a large thrust fault.

DISCUSSION AND CONCLUSIONS

Regional and detailed mapping of the Gataga area has confirmed the structural interpretations of the 1985 fieldwork (McClay and Insley, 1986) and has redefined the stratigraphy of the area.

Phase 1 deformation produces local zones of steep fold plunges and may be related to either syndepositional deformation during the mid-Devonian extension or to early thrust deformation during the emplacement of the large thrust sheets of Cambrian strata. Further analysis is required to resolve this problem.

The dominant Mesozoic thrusting and folding of Phase 2 deformation has produced both southwestward and northeastward tectonic transport on the margins of the Kechika trough. There is a strong lithostratigraphic control on deformation style with the massive competent carbonate units forming thick thrust panels whereas the fine-grained siliciclastics in the central fold and thrust belt are tightly folded, cleaved and faulted. This "palaeo-triangle zone" of ductile Road River and Earn Group rocks in the Kechika trough acted as a buffer zone between the two opposing thrust complexes to the northeast and southwest. Continued deformation on underlying "blind thrusts" beneath the exposed section rotated and steepened the thrust sheets at the present surface (Figure 3-7-6).

Phase 3 deformation may be interpreted in terms of a dextral shear couple associated with late Cretaceous dextral strike-slip faulting along the Rocky Mountain Trench (Gabrielse, 1985).

Within the Kechika trough, the Middle to Late Devonian Lower Earn Group siliciclastics thicken and coarsen westwards suggesting that they were deposited in extensional half-grabens. Further analysis of measured sections and of sedimentological data is needed to develop a tectono-sedimentary model for these units and for the stratiform mineralization found in the Devonian.

FUTURE RESEARCH

Future research will involve the palinspastic reconstruction of the Gataga map area involving the construction and restoration of balanced sections; determination of the detailed structural evolution of the area; analysis of the detailed sedimentology from measured sections; and geochemical and isotopic analysis of the stratiform mineralization. These techniques will be used to erect and test models for the tectonics, sedimentation and mineralization of this part of the Kechika trough.

ACKNOWLEDGMENTS

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BABINE PROJECT*
(93L/10, 15)

By D. G. MacIntyre, D. Brown, P. Desjardins and P. Mallett

INTRODUCTION

This report summarizes work completed on the Babine Project during the 1986 field season. This project began in 1984 and was restricted to the Dome Mountain gold camp (MacIntye, 1985). Between July 4 and September 10, 1986, four geologists mapped the area shown in Figure 3-8-1 at 1 to 1:20 000 scale. The work was done from the town of Smithers using four-wheel-drive vehicles and helicopters for access. A total of 1350 geological stations have now been established within an area of approximately 900 square kilometres. The field data have been stored in computer files and can be obtained as a printout or on floppy disk in ASCII format. Mapping will continue to the north and south in 1987.

The objective of the Babine project is to develop a metallogenic model for the wide variety of mineral deposit types present in the Babine Range. The initial phase of this project was concerned with gold-bearing quartz veins of the Dome Mountain gold camp (MacIntyre, 1985). This work continued in 1986 with examination and sampling of drill core from the Forks, Boulder Creek and 9800 veins. Other properties in the map area were also visited and sampled. The Babine Project was partially funded by the Canada/British Columbia Mineral Development Agreement.

REGIONAL GEOLOGIC SETTING

West central British Columbia is part of the Stikine terrane. This terrane includes: submarine calc-alkaline to alkaline immature volcanic island arc rocks of the Late Triassic Takla Group; subaerial to submarine calc-alkaline volcanic, volcaniclastic and sedimentary rocks of the Early to mid-Jurassic Hazelton Group; Late Jurassic and Early Cretaceous successor basin sedimentary rocks of the Bowser Lake, Skeena, and Sustut Groups; and Late Cretaceous to Tertiary calc-alkaline continental volcanic arc rocks of the Kasalka, Ootsa Lake and Goosly Lake Groups. The younger volcanic rocks occur sporadically throughout the area, mainly in downdropped fault blocks and grabens. Plutonic rocks of Jurassic, Cretaceous and Tertiary age are known and form distinct intrusive belts or provinces (Carter, 1981). Mineral deposits include mesothermal and epithermal precious metal veins, porphyry copper and molybdenum deposits and stratabound polymetallic massive sulphide deposits. The general geology of west central British Columbia is shown in Figure 3-8-1.

GEOLOGY OF THE BABINE RANGE

The Babine Range is a northwest-trending horst of folded and faulted Jurassic and Cretaceous volcanic and sedimentary rocks bounded to the west and east by grabens containing Late Cretaceous and younger rocks. The structural setting is similar to the Basin and Range province of the United States and is probably related to extensional tectonics induced by right lateral movement on major north-trending transcurrent faults.

The geology of the Babine Range is characterized by asymmetric, southeast-plunging open folds that are truncated by northeast and northwest-trending high-angle faults (Figure 3-8-2). A progressive downward displacement of tilted fault blocks occurs to the northwest, with progressively younger rocks being preserved immediately northwest of the faults. Thus progressively higher stratigraphic levels are exposed going northwards into the Bowser Basin and away from the Skeena Arch.

An idealized north-south cross-section (Figure 3-8-3) shows the inferred stratigraphic relationships and position of mineral deposits in the 1986 study area. It is based on lithology and crosscutting relationships; fossil identifications and radiometric age dates are not yet available.

PRE-HAZELTON ROCKS

Greenstone-Sill Complex (TrJsc)

The oldest rocks in the Babine Range may be exposed on the steep north-facing slope of Mount McKendrick, where a thick section of south-dipping greenstones, containing numerous leucogranite sills, is overlain by a polymictic boulder conglomerate. The conglomerate contains flattened leucogranite and greenstone clasts suggesting it is an erosion surface at the top of the greenstone-sill complex. The conglomerate may be the basal member of the Early Jurassic Telkwa Formation. Both the greenstones and conglomerates are foliated and have similar styles of folding suggesting they have been through the same deformational event. A sample of leucogranite has been collected for uranium-lead age-dating of zircons. The greenstones are tentatively assigned to the Late Triassic Takla Group.

HAZELTON GROUP

The Hazelton Group (Leach, 1910) is an island-arc assemblage that was deposited in the northwest-trending Hazelton trough in early to middle Jurassic time. Tipper and Richards (1976) divide the group into three major formations in the Smithers map-area (93L). These are the Late Sinemurian to Early Pliensbachian Telkwa Formation, the Early Pliensbachian to Middle Toarcian Nilkitkwa Formation, and the Middle Toarcian to Lower Callovian Smithers Formation.

TELKWA FORMATION

The Telkwa Formation, which is comprised of subaerial and submarine pyroclastic and flow rocks with lesser intercalated sediments, is the thickest and most extensive formation of the Hazelton Group. The mixed subaerial to submarine Babine Shelf facies of the Telkwa Formation, which separates the subaerial Howson facies to the west from the submarine Kotsine facies to the east, underlies the Babine Range (Tipper and Richards, 1976).

We have subdivided the Telkwa Formation into four map units. These are: (1) polymictic conglomerate (lJT1); (2) porphyritic andesite (lJT2); (3) fragmental volcanic rocks (lJT3); and (4) phyllitic maroon tuff (lJT4). Units 1 and 4 are believed to be present throughout the map area; Units 2 and 3 are interpreted to be facies that are restricted to major volcanic centres with lithological variations reflecting thinning and fining away from eruptive vents.

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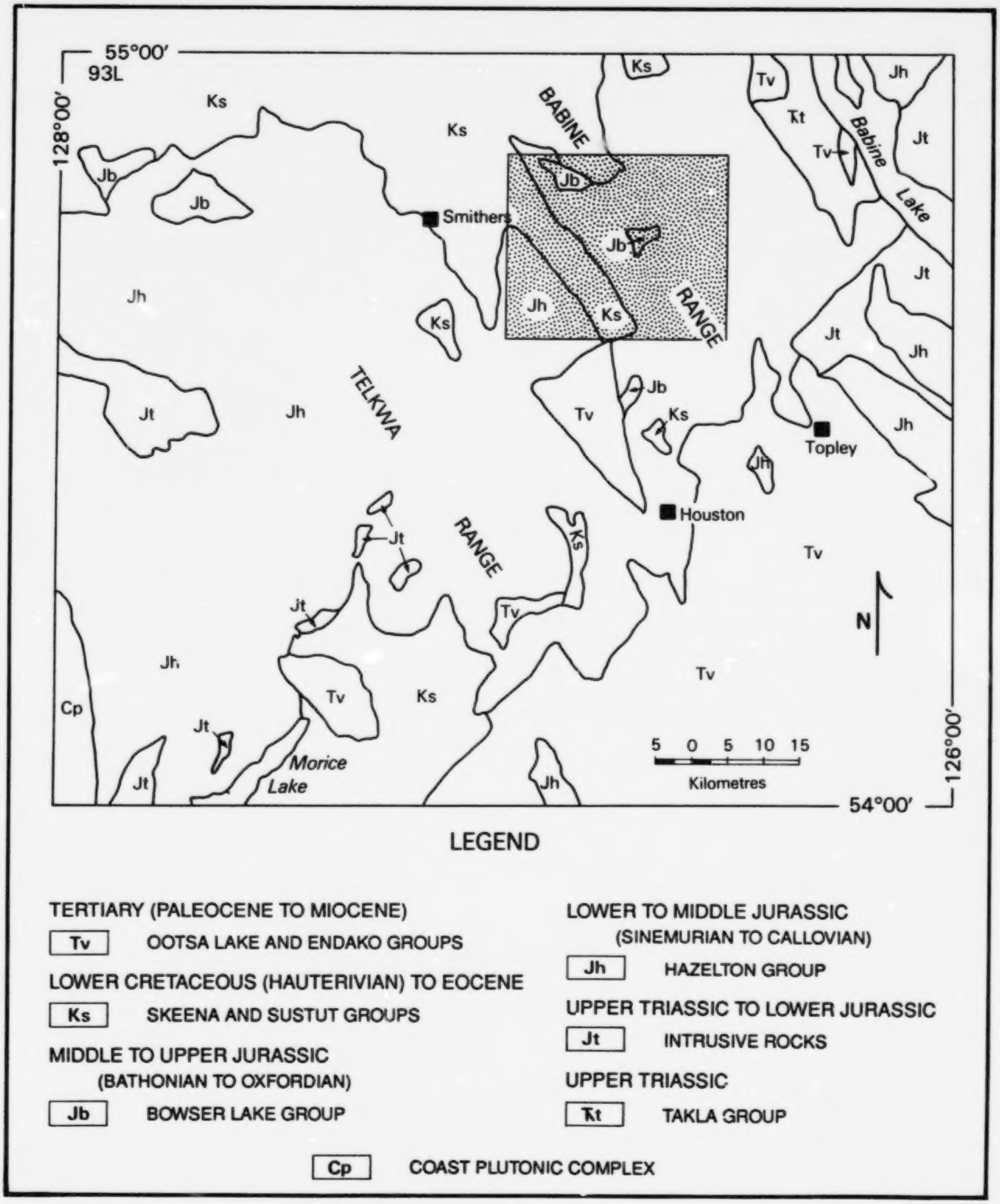
* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.


55°00′
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Ks
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BABINE
RANGE
TELKWA
RANGE
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Lake
Morice
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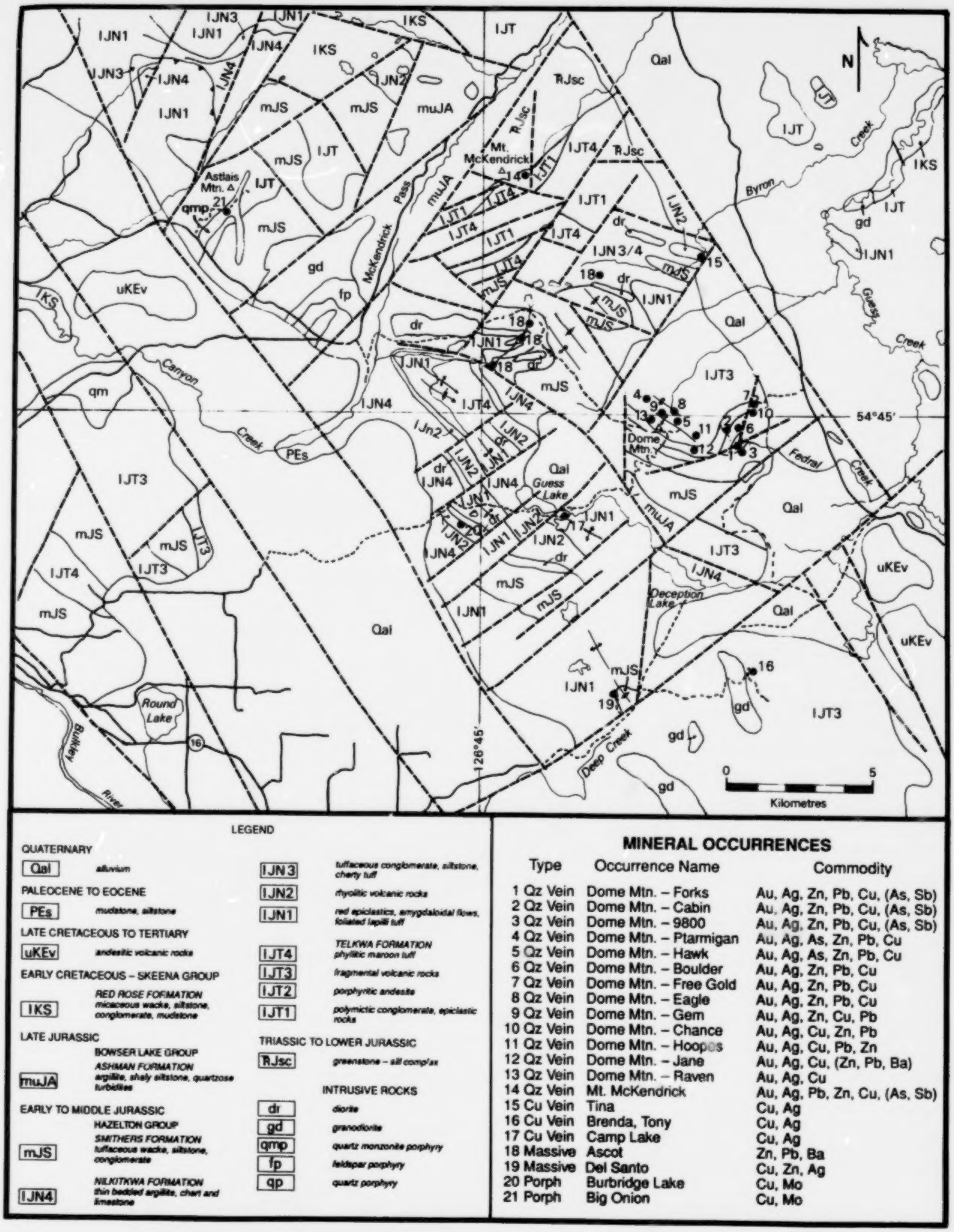
N
5 0 5 10 15
Kilometres
LEGEND
TERTIARY (PALEOCENE TO MIOCENE)
Tv OOTSA LAKE AND ENDAKO GROUPS
LOWER CRETACEOUS (HAUTERIVIAN) TO EOCENE
Ks SKEENA AND SUSTUT GROUPS
MIDDLE TO UPPER JURASSIC
(BATHONIAN TO OXFORDIAN)
Jb BOWSER LAKE GROUP
LOWER TO MIDDLE JURASSIC
(SINEMURIAN TO CALLOVIAN)
Jh HAZELTON GROUP
UPPER TRIASSIC TO LOWER JURASSIC
Jt INTRUSIVE ROCKS
UPPER TRIASSIC
Ŧt TAKLA GROUP
Cp COAST PLUTONIC COMPLEX

Figure 3-8-1. Location of the Babine Project and general geology of the Smithers map area.


lJN1
lJN3
lJN4
lKS
lJT
Qal
ƦJsc
mJS
muJA
lJN2
Mt. McKendrick
Astlais Mtn.
qmp
lJT1
lJT4
lJT3
dr
gd
fp
McKendrick Pass
lJN 3/4
uKEv
lKS
Canyon Creek
qm
PEs
Dome Mtn.
Guess Lake
Deception Lake
Byron Creek
Guess Creek
Fedral Creek
Deep Creek
Round Lake
Bulkley River
16
128°45'
54°45'
N
0
5
Kilometres
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

LEGEND

QUATERNARY

Qal *alluvium*

PALEOCENE TO EOCENE

PEs *mudstone, siltstone*

LATE CRETACEOUS TO TERTIARY

uKEv *andesitic volcanic rocks*

EARLY CRETACEOUS – SKEENA GROUP

RED ROSE FORMATION

lKS *micaceous wacke, siltstone, conglomerate, mudstone*

LATE JURASSIC

BOWSER LAKE GROUP

ASHMAN FORMATION

muJA *argillite, shaly siltstone, quartzose turbidites*

EARLY TO MIDDLE JURASSIC

HAZELTON GROUP

SMITHERS FORMATION

mJS *tuffaceous wacke, siltstone, conglomerate*

NILKITKWA FORMATION

lJN4 *thin bedded argillite, chert and limestone*

lJN3 *tuffaceous conglomerate, siltstone, cherty tuff*

lJN2 *rhyolitic volcanic rocks*

lJN1 *red epiclastics, amygdaloidal flows, foliated lapilli tuff*

TELKWA FORMATION

lJT4 *phyllitic maroon tuff*

lJT3 *fragmental volcanic rocks*

lJT2 *porphyritic andesite*

lJT1 *polymictic conglomerate, epiclastic rocks*

TRIASSIC TO LOWER JURASSIC

ƦJsc *greenstone – sill complex*

INTRUSIVE ROCKS

dr *diorite*

gd *granodiorite*

qmp *quartz monzonite porphyry*

fp *feldspar porphyry*

qp *quartz porphyry*

MINERAL OCCURRENCES

	Type	Occurrence Name	Commodity
1	Qz Vein	Dome Mtn. – Forks	Au, Ag, Zn, Pb, Cu, (As, Sb)
2	Qz Vein	Dome Mtn. – Cabin	Au, Ag, Zn, Pb, Cu, (As, Sb)
3	Qz Vein	Dome Mtn. – 9800	Au, Ag, Zn, Pb, Cu, (As, Sb)
4	Qz Vein	Dome Mtn. – Ptarmigan	Au, Ag, As, Zn, Pb, Cu
5	Qz Vein	Dome Mtn. – Hawk	Au, Ag, As, Zn, Pb, Cu
6	Qz Vein	Dome Mtn. – Boulder	Au, Ag, Zn, Pb, Cu
7	Qz Vein	Dome Mtn. – Free Gold	Au, Ag, Zn, Pb, Cu
8	Qz Vein	Dome Mtn. – Eagle	Au, Ag, Zn, Pb, Cu
9	Qz Vein	Dome Mtn. – Gem	Au, Ag, Zn, Cu, Pb
10	Qz Vein	Dome Mtn. – Chance	Au, Ag, Cu, Zn, Pb
11	Qz Vein	Dome Mtn. – Hoopes	Au, Ag, Cu, Pb, Zn
12	Qz Vein	Dome Mtn. – Jane	Au, Ag, Cu, (Zn, Pb, Ba)
13	Qz Vein	Dome Mtn. – Raven	Au, Ag, Cu
14	Qz Vein	Mt. McKendrick	Au, Ag, Pb, Zn, Cu, (As, Sb)
15	Cu Vein	Tina	Cu, Ag
16	Cu Vein	Brenda, Tony	Cu, Ag
17	Cu Vein	Camp Lake	Cu, Ag
18	Massive	Ascot	Zn, Pb, Ba
19	Massive	Del Santo	Cu, Zn, Ag
20	Porph	Burbridge Lake	Cu, Mo
21	Porph	Big Onion	Cu, Mo

Figure 3-8-2. Preliminary geology of the Babine Range.

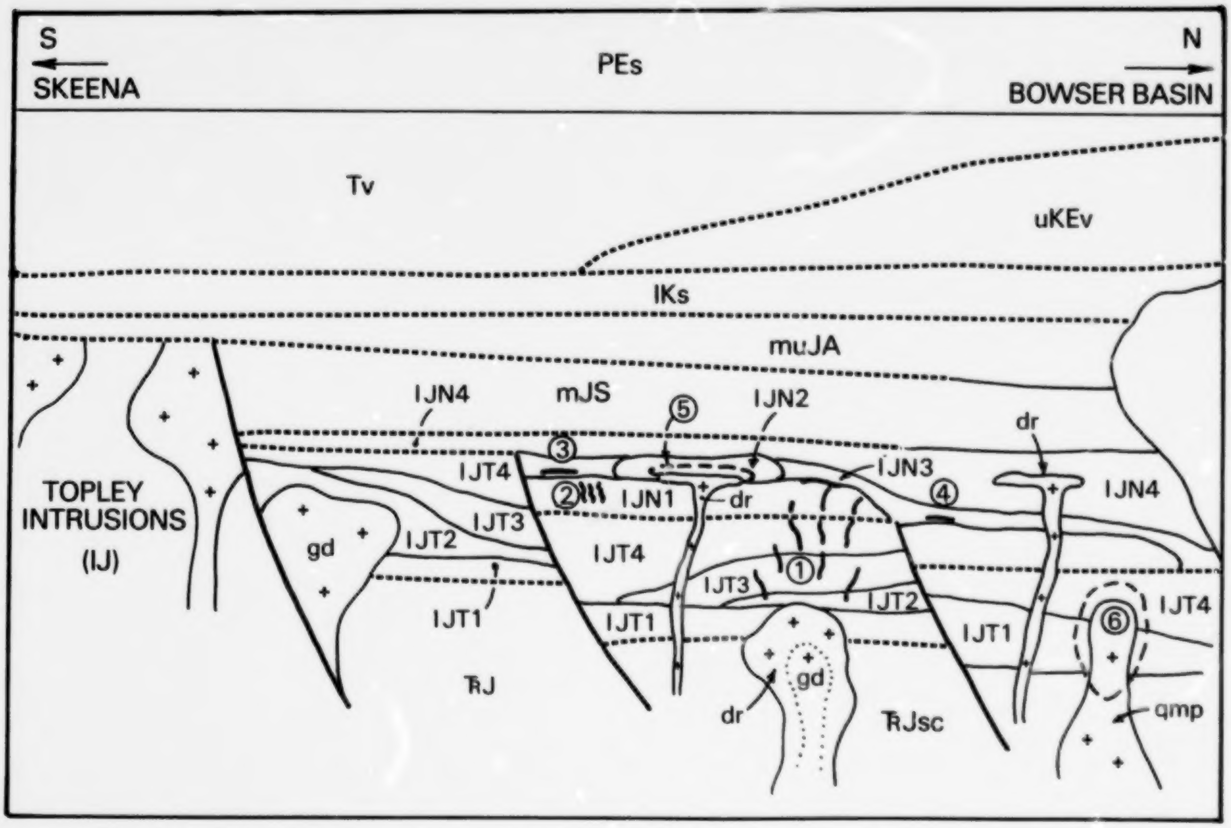


Figure 3-8-3. Schematic north-south cross section showing stratigraphic relationships and position of mineral deposits.

Polymictic Conglomerate Unit (lJT1)

The polymictic conglomerate unit is well-exposed south of Mount McKendrick. It is characterized by clasts of leucogranite and greenstone that are identical to the underlying greenstone-sill complex (TrJgs). The conglomerate is strongly deformed and clasts are flattened parallel to foliation planes. Clasts are up to 20 centimetres in diameter immediately above the greenstone sill complex and gradually decrease in size up section.

Porphyritic Andesite Unit (lJT2)

In the Babine Range, fragmental volcanic rocks of the Telkwa Formation contain mainly porphyritic andesite clasts, even though flows of porphyritic andesite are rare. A massive andesite flow does occur near the Free Gold vein but elsewhere the Telkwa Formation is predominantly fragmental. Flows may have been restricted to the immediate vicinity of eruptive centres, forming volcanic cones or stratovolcanoes. The volcanic edifices were probably largely eroded prior to the Nilkitkwa marine transgression, thus explaining the preponderance of porphyritic andesite detritus in Telkwa and Nilkitkwa epiclastic rocks.

Fragmental Volcanic Unit (lJT3)

A chaotic assemblage of lahar, tuff-breccia and lapilli tuff, with lesser intercalations of lithic, crystal and ash tuff and volcanic-derived sedimentary rocks, crops out on Dome Mountain. These rocks are purple, mauve, green and grey and contain clasts of porphyritic andesite or crystal tuff that range from less than 1 centimetre to 35 to 40 centimetres in diameter in a fine-grained matrix of feldspar crystal and lithic fragments. In places the clasts are flattened and elongate parallel to bedding. Beds comprised of large rounded bombs up to 30 centimetres in diameter, floating in a fine-grained ash matrix, are not uncommon. Finer grained tuff beds within the unit are strongly foliated subparallel to bedding.

Coarse fragmental rocks underlie Dome Mountain. These rocks are probably proximal to an eruptive centre and may be part of an eroded stratovolcano. Some of the beds appear to be primary having been deposited as hot, gas-charged flows; other beds are clearly reworked and represent secondary erosional deposits. The fragmental rocks thin and fine to the north and west, further evidence that Dome Mountain represents a major volcanic centre.

In general, fragmental rocks of the Telkwa Formation become finer grained northwards along the Babine Range. This suggests that the Skeena Arch, which transects the southern end of the range, may have been a volcanic arc in early Jurassic time. Volcanic detritus was apparently shed north and northeastward into a back arc basin (Bowser Basin and Hazelton trough).

Phyllitic Maroon Tuff Unit (lJT4)

The conglomerate (lJT1) and coarse fragmental units (lJT3) are both overlain by fine-grained phyllitic red to maroon tuff or epiclastics. These rocks have a well-developed slaty cleavage and are typically tightly folded. The maroon tuff may have been deposited late in the evolution of the Hazelton calc-alkaline volcanic arc, in a predominantly subaerial environment.

The Geological Survey of Canada has mapped the maroon tuff unit as the Toarcian red tuff member of the upper Nilkitkwa Formation but the present study suggests that in this area, it is part of the upper Telkwa Formation. Our interpretation is that the maroon tuff stratigraphically underlies sedimentary strata containing a Late Pliensbachian pelecypod (Tipper, personal communication), therefore the maroon tuff must be at least Pliensbachian or older.

NILKITKWA FORMATION

The Nilkitkwa Formation conformably to disconformably overlies the Telkwa Formation and is an important host for mineral occurrences in the Babine Range. West of the Babine Range it is comprised of predominantly red epiclastic rocks; to the east it includes Early Pliensbachian to mid-Toarcian transgressive marine sedimentary rocks that overlie rhyolite and basalt flows and red epiclastic rocks.

We have subdivided the Nilkitkwa Formation into four map units. These are: (1) interbedded red epiclastics and amygdaloidal flows (lJN1); (2) rhyolitic volcanic rocks (lJN2); (3) tuffaceous conglomerate, cherty tuff and siltstone (lJN3); and (4) thin-bedded argillite, chert and limestone (lJN4).

Red Epiclastic and Amygdaloidal Flow Unit (lJN1)

A distinctive unit of well-bedded red epiclastic rocks and green to maroon amygdaloidal flows and welded tuffs overlies phyllitic maroon tuffs of the Telkwa Formation. This unit is well exposed on the south slope of Dome Mountain, in Fedral Creek above and below the Forks showing, along the height of land south of Guess Lake and northwest of Astlais Mountain (Figure 3-8-2).

Previous workers have mapped the red epiclastic/amygdaloidal flow unit as part of the Telkwa Formation. In this study it is mapped as the basal part of Nilkitkwa Formation because: (1) the red epiclastic rocks represent erosion of the Telkwa Formation in a subaerial environment; (2) the amygdaloidal flows are compositionally distinct from the calc-alkaline rocks of the Telkwa Formation and represent a change to rift-type volcanism; and (3) the amygdaloidal flows were deposited in a submarine environment during the early stages of the Nilkitkwa marine transgression. The amygdaloidal flows are lithologically similar to the Carruthers Member of the Nilkitkwa Formation as described by Tipper and Richards (1976).

Rhyolitic Volcanic Unit (lJN2)

Locally flow-banded rhyolite and cherty tuff overlies the red epiclastic/amygdaloidal flow unit. Near Burbridge Lake the rhyolite is welded with flattened clasts that are typically replaced by limonite. The rhyolites dip southwest and may be several hundred metres thick. Limy siltstones and argillites crop out further southwest and appear to overlie the rhyolite unit. A thick section of massive rhyolite overlain by thin-bedded chert and limy siltstone is also exposed in lower Byron Creek. Elsewhere the rhyolites are absent or very thin. At Dome Mountain a mottled cherty tuff occurs at the same stratigraphic position as the rhyolitic volcanic rocks and may be their distal equivalent.

We have interpreted the rhyolites to be domes that were built on a mafic volcanic pile. Angular felsic clasts in laterally equivalent conglomerates were probably derived from erosion of these domes; alternatively the clasts may be of an airborne origin, related to explosive eruption at felsic volcanic centres. Small stratabound polymetallic massive sulphide occurrences are found at the same stratigraphic position as the rhyolites.

Tuffaceous Conglomerate — Siltstone (lJN3)

A thin unit of brown to buff-weathering granule to pebble conglomerate, with intercalated beds of volcanic wacke and siltstone, overlies the red epiclastic/amygdaloidal flow unit. These sedimentary rocks typically contain angular felsic clasts in a silty matrix. At Dome Mountain, near the Forks showing, this unit contains poorly preserved Pliensbachian pelecypods (*Jaworskiella* cf. *J. siemonmulleri* Poulton, identification by H. Tipper, Geological Survey of Canada). The fossiliferous beds overlie beds of mottled cherty tuff.

Thin-Bedded Argillite, Chert and Limestone Unit (lJN4)

A recessive unit of thin-bedded, rusty weathering silty argillite, with minor dark chert and argillaceous limestone interbeds, overlies the lower volcanic members of the Nilkitkwa Formation. The unit typically has a well-developed slaty cleavage, tight small-scale fold structures, and disseminated and laminated pyrite. Fossils are generally absent.

The Babine Range is near the western and southern limit of the Nilkitkwa Formation (Tipper and Richards, 1975). West of the range, near Round Lake, siltstones containing Bajocian age fossils (Tipper, personal communication) overlie Telkwa Formation rocks; the Nilkitkwa Formation is absent. South of Guess Lake the lower volcanic members of the Nilkitkwa Formation are present but these rocks are overlain by probable Smithers Formation or younger strata; the conglomerate and thin-bedded rusty argillite units of the Nilkitkwa Formation are absent or very thin. This suggests exposure and erosion of Nilkitkwa Formation along the northern margin of the Skeena Arch during a late Early to early Middle Jurassic marine regression.

SMITHERS FORMATION (mJS)

In the northern part of the Babine Range, the Smithers Formation, which is predominantly Bajocian in age, disconformably overlies the Nilkitkwa Formation. It is comprised of fossiliferous sandstone and siltstone, with lesser intercalated felsic tuff, that was deposited during a marine regression. To the south and west of the Babine Range, the Smithers Formation rests directly on Telkwa Formation or is absent.

North of Guess Lake, up to 300 metres of monotonous, medium to thick-bedded, orange to brown-weathering, dark grey limy siltstone and mudstone overlies rusty thin-bedded graphitic argillite, chert and limestone of the Nilkitkwa Formation. This unit is relatively resistant; it forms the south spur of Dome Mountain and caps ridges in the area east of Canyon Creek. The siltstone has a slaty cleavage in places. Fossils collected in the area northwest of Dome Mountain have been tentatively identified as Middle Jurassic (Tipper, personal communication). These rocks are therefore assigned to the Smithers Formation. Our previous work on Dome Mountain (MacIntyre, 1985) included these rocks with the Nilkitkwa Formation, but we now place the Nilkitkwa-Smithers boundary at the top of the thin-bedded, rusty argillite unit as defined in this study.

On Dome Mountain, the thick-bedded siltstone grades up section into a relatively thin unit of well-bedded dark grey argillaceous limestone, limy siltstone, and wacke, with a few thin beds of pebble conglomerate and chert. These rocks crop out near the southeast end of Dome Mountain ridge and in the lower road cuts on the southwest slope, above Marjorie Creek. The limestone beds weather in positive relief producing a ribbed appearance on outcrop surfaces. These rocks are also included with the Smithers Formation.

Massive, poorly bedded, light green, calcareous crystal tuff or volcanic wacke, with rare intercalations of argillaceous limestone and shaly siltstone, characterizes the upper part of the Smithers Formation on Dome Mountain. The succession is estimated to be at least 500 metres thick.

Well-bedded fossiliferous siltstones and wackes of the Smithers Formation are exposed in a downdropped, wedge-shaped fault block northeast of Astlais Mountain (Figure 3-8-2). These rocks are in fault contact with Nilkitkwa and Telkwa Formation rocks to the northwest and southeast respectively.

BOWSER LAKE GROUP

Within the Hazelton trough, successor basin deposits of the Bowser Lake Group (Duffell and Souther, 1964) conformably overlie the Smithers Formation. These rocks range in age from Late

Bajocian to Early Oxfordian. Only the lowermost Ashman Formation is present in the study area. It was deposited during a mid-Jurassic marine transgression that apparently advanced as far south as the Skeena Arch (Tipper and Richards, 1976). To the west, within the Telkwa basin, both the Smithers and Ashman Formations are absent and Early Cretaceous rocks of the Skeena Group rest directly on Telkwa Formation or the lower volcanic members of the Nilkitkwa Formation (Jahak Koo, personal communication).

ASHMAN FORMATION (muJA)

In the Babine Range, the Ashman Formation is mainly dark grey to black shale with lesser intercalations of quartzose wacke and chert-pebble conglomerate. These quartz and chert-bearing turbidite interbeds distinguish this unit from lithologically similar, thin-bedded shales and argillites of the Nilkitkwa Formation. The Ashman Formation is also more fossiliferous.

In the absense of fossils, the Ashman Formation is difficult to distinguish from the overlying Red Rose Formation of the Skeena Group which is also mapped as black shale and chert-pebble conglomerate. The coarse clastic beds of the Red Rose Formation often contain detrital mica and this has been used by other workers to distinguish the two formations.

The black shales and quartzose turbidites exposed northeast of Astlais Mountain, northwest of Dome Mountain and immediately north of Mount McKendrick, are tentatively assigned to the Ashman Formation because they are nonmicaceous and contain some fossils of probable late Jurassic age (Tipper, personal communication).

The Ashman Formation was deposited during a major marine transgression. On Grouse Mountain, immediately south of the 1986 map area, Lower Callovian rocks of the Ashman Formation rest directly on Telkwa Formation suggesting considerable southern advancement of the sea onto the Skeena Arch. Tipper and Richards (1975) report the occurrence of clasts of Topley granite in Ashman rocks, indicating erosion and unroofing of the Hazelton volcanic arc had begun by late Middle Jurassic time.

SKEENA GROUP

The Skeena Group (Leach, 1910) comprises interbedded marine and nonmarine sedimentary strata of an Early Cretaceous successor basin. West of Telkwa these rocks unconformably overlie Telkwa volcanic rocks and contain important coal seams (Koo, 1984). The coal seams occur in upward-fining fluvial clastic sequences of conglomerate, sandstone, siltstone and mudstone.

RED ROSE FORMATION (lKS)

The Geological Survey of Canada has mapped much of the area north of McKendrick Pass as the Red Rose Formation (Sutherland Brown, 1960) of the Skeena Group. It is uncertain what criteria have been used to establish the age of these rocks. Lithologies within the area mapped as Red Rose vary from well-bedded sandstone, mudstone and pebble conglomerate to graphitic black shale. In this study, the black shale is mapped as Ashman and Nilkitkwa Formations.

Skeena Group sandstones and mudstones, with well-preserved shelly fossils, also crop out along Guess Creek where it cuts through the plateau area east of the Babine Range. These rocks contain seams of sub-bituminous coal that have been upgraded to meta-anthracite near rhyolite dykes (G. White, personal communication).

LATE CRETACEOUS TO TERTIARY ROCKS

Late Cretaceous to Tertiary volcanic and sedimentary rocks are preserved within the Driftwood Creek graben (name proposed in this study), immediately west of the Babine Range. Similar rocks may also underlie much of plateau area east of the range.

Flow-banded rhyolites crop out in a low-lying area west of Astlais Mountain. They are tentatively correlated with the Eocene Ootsa Lake Group. These rocks appear to be altered and may have some epithermal vein potential.

Paleocene mudstone and shale crop out along Canyon and Driftwood Creeks. The Driftwood Creek exposures contain well-preserved plant, fish and insect fossils.

Lapilli tuffs and porphyritic andesite flows crop out southeast of Deception Lake; prominent quartz eyes distinguish them from Jurassic volcanic rocks. They are tentatively mapped as Late Cretaceous to Tertiary and may correlate with the Brian Boru (Sutherland Brown, 1960) or Tip Top Hill volcanic rocks (Church, 1970). The aeromagnetic signature of this area is also consistent with the presence of young volcanic rocks, with frequent reversals in magnetism producing an irregular pattern of highs and lows.

DIORITIC INTRUSIONS

Several small elongate dykes or sills of fine to medium-grained diorite or diabase intrude Hazelton Group rocks in the Babine Range. The sills are often foliated parallel to their contacts. These intrusions cut the Nilkitkwa, Smithers and possibly Ashman Formations and are therefore younger than Middle Jurassic. The diorites have a pervasive foliation which has the same orientation as their host rocks. Similar intrusions occur in the Tahtsa Lake area and are genetically related to earliest Late Cretaceous volcanic rocks of the Kasalka Group (MacIntyre, 1985).

GRANITIC INTRUSIONS

Several multiphase granitic intrusions crop out southeast of Astlais Mountain, on the Big Onion property. One of these, a northeast-trending, altered quartz-feldspar porphyry to porphyritic quartz diorite dyke cuts hornfelsed Telkwa volcanic rocks. The University of British Columbia geochronology laboratory has calculated a potassium-argon isotopic age of 117 ± 4 million years (Ma) on a whole rock sample of the sericite-altered porphyry and 74.7 ± 2.6 Ma on biotite from a small, unaltered hornblende granodiorite stock to the east (samples collected in 1977 and 1979 by Dr. Colin Godwin, The University of British Columbia). Biotite extracted from a postmineral quartz monzonite dyke that cuts these intrusions gave an isotopic age of 48.7 ± 1.9 Ma (Carter, 1981). The geochronology laboratory has also dated biotite from a small granodiorite stock on the Del Santo property at 47.1 ± 1.6 Ma. The older granitic rocks correlate with the Bulkley intrusions as defined by Carter (1981); the younger ages with the Nanika intrusions.

The Geological Survey of Canada has mapped several granitic intrusions south of Deep Creek as correlative with the early Jurassic Topley intrusions (Carter, 1981). This correlation is based on lithological similarity. The Eocene age determined for the granodiorite at Del Santo suggests some of these intrusions may be much younger than Jurassic.

DYKES

Dykes of basalt, andesite and rhyolite with varying orientations cut Cretaceous and younger rocks in the Babine Range. The dykes may have been feeders to Tertiary flows.

STRUCTURE

Phyllitic maroon tuff and thin-bedded, fine-grained argillaceous rocks of the Babine Range have a well-developed slaty cleavage. This early cleavage has been folded into tight asymmetric and locally recumbent minor folds that generally plunge gently to moderately to the southeast and east (Figure 3-8-4). A weakly developed crenulation or fracture cleavage, axial planar to minor folds, dips steeply northeast. These minor folds reflect the presence of larger

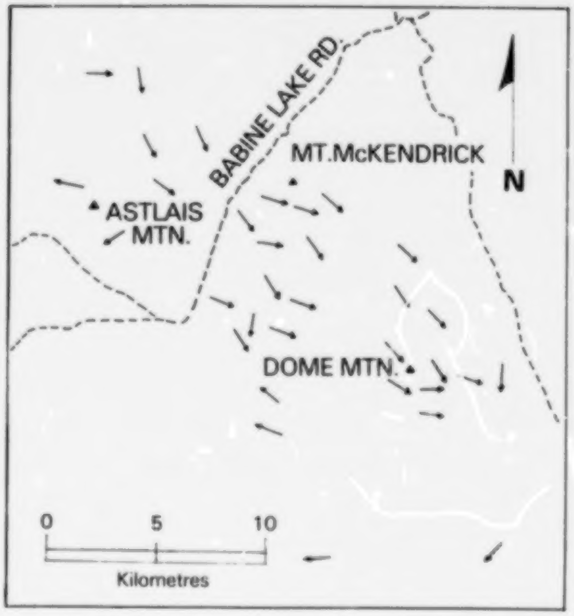


Figure 3-8-4. Fold axis trends, Babine Range.

asymmetric folds with similar orientation. The folds are cut and offset by northeast-trending, high-angle faults which are roughly parallel to a prominent C-joint direction.

The Geological Survey of Canada (Open File 351) has mapped several southwest-dipping thrust faults. No compelling evidence for these faults was observed during the mapping program. In fact, if the orientation of fold structures has been correctly interpreted, northeast rather than southwest-dipping thrusts would be expected. There are probably numerous thrusts and bedding plane detachments within incompetent fine-grained clastic units, but the amount of displacement is probably quite small. Almost all of the contacts between geologic units in the Babine Range are faults, but most of these are high-angle normal, reverse and transcurrent faults; few, if any, appear to be true thrust faults.

The most prominent joint orientation is northeast, roughly perpendicular to major fold axes. These steep, northwest-dipping C-joints also parallel prominent airphoto linears and several major high-angle faults which offset the stratigraphy.

The timing of folding and faulting is not well established. However, elsewhere in west-central British Columbia, folding and uplift occurred after Albian time and before construction of the Late Cretaceous continental volcanic arc (MacIntyre, 1985). Block faulting and Basin and Range type extensional tectonics are probably latest Cretaceous to Tertiary in age. Some rifting and extrusion of basalt may have accompanied basin subsidence in the Jurassic and early Cretaceous, but these early faults are difficult to recognize because of the younger tectonic overprint. Some of the quartz veins on Dome Mountain have been folded and broken suggesting some of the mineralization within the camp predates deformation.

METALLOGENY OF THE BABINE RANGE

Mineral deposits in the Babine Range can be subdivided into six groups (Table 3-8-1). These are: (1) mesothermal gold-silver-bearing quartz veins; (2) copper-silver veins in mafic and felsic volcanic rocks; (3) copper-zinc-silver massive sulphide deposits associated with mafic flows; (4) polymetallic massive sulphide occurrences associated with rhyolitic volcanic rocks; (5) porphyry copper-molybdenum deposits associated with dioritic sills; and (6) porphyry copper-molybdenum deposits associated with quartz monzonite intrusions. The stratigraphic position of these deposits is shown diagrammatically in Figure 3-8-3.

MESOTHERMAL QUARTZ VEINS

DOME MOUNTAIN CAMP

The geology and mineral deposits of the Dome Mountain camp have been described in a previous report (MacIntyre, 1985). This report focuses on recent exploration, mainly on the Forks, Boulder Creek and 9800 showings. The location of quartz veins on Dome Mountain is shown in Figure 3-8-5. Characteristics of the veins are summarized in Table 3-8-1.

TABLE 3-8-1 — MINERAL OCCURRENCES IN THE STUDY AREA

Type	Occurrence Name	Commodity	Host
1 QZ VEIN	Dome Mtn. — Forks	Au, Ag, Zn, Pb, Cu, (As, Sb)	lJN1
1 QZ VEIN	Dome Mtn. — Cabin	Au, Ag, Zn, Pb, Cu, (As, Sb)	lJT4
1 QZ VEIN	Dome Mtn. — 9800	Au, Ag, Zn, Pb, Cu, (As, Sb)	lJN4
1 QZ VEIN	Dome Mtn. — Ptarmigan	Au, Ag, As, Zn, Pb, Cu	lJT3
1 QZ VEIN	Dome Mtn. — Hawk	Au, Ag, As, Zn, Pb, Cu	lJT3
1 QZ VEIN	Dome Mtn. — Boulder	Au, Ag, Zn, Pb, Cu	lJN1
1 QZ VEIN	Dome Mtn. — Free Gold	Au, Ag, Zn, Pb, Cu	lJT2
1 QZ VEIN	Dome Mtn. — Eagle	Au, Ag, Zn, Pb, Cu	lJT3
1 QZ VEIN	Dome Mtn. — Gem	Au, Ag, Zn, Cu, Pb	lJT3
1 QZ VEIN	Dome Mtn. — Chance	Au, Ag, Cu, Zn, Pb	lJT3
1 QZ VEIN	Dome Mtn. — Hoopes	Au, Ag, Cu, Pb, Zn	lJT3
1 QZ VEIN	Dome Mtn. — Jane	Au, Ag, Cu, (Zn, Pb, Ba)	lJT4
1 QZ VEIN	Dome Mtn. — Raven	Au, Ag, Cu	lJT3
1 QZ VEIN	Mt. McKendrick	Au, Ag, Pb, Zn, Cu, (As, Sb)	TrJ?
2 CU VEIN	Tina	Cu, Ag	lJN2
2 CU VEIN	Brenda, Tony	Cu, Ag	lJN1
2 CU VEIN	Camp Lake	Cu, Ag	lJN1
3 MASSIVE	Ascot	Zn, Pb, Ba	lJN4
4 MASSIVE	Del Santo	Cu, Zn, Ag	lJN1
5 PORPH	Burbridge Lake	Cu, Mo	lJN2
6 PORPH	Big Onion	Cu, Mo	lJT

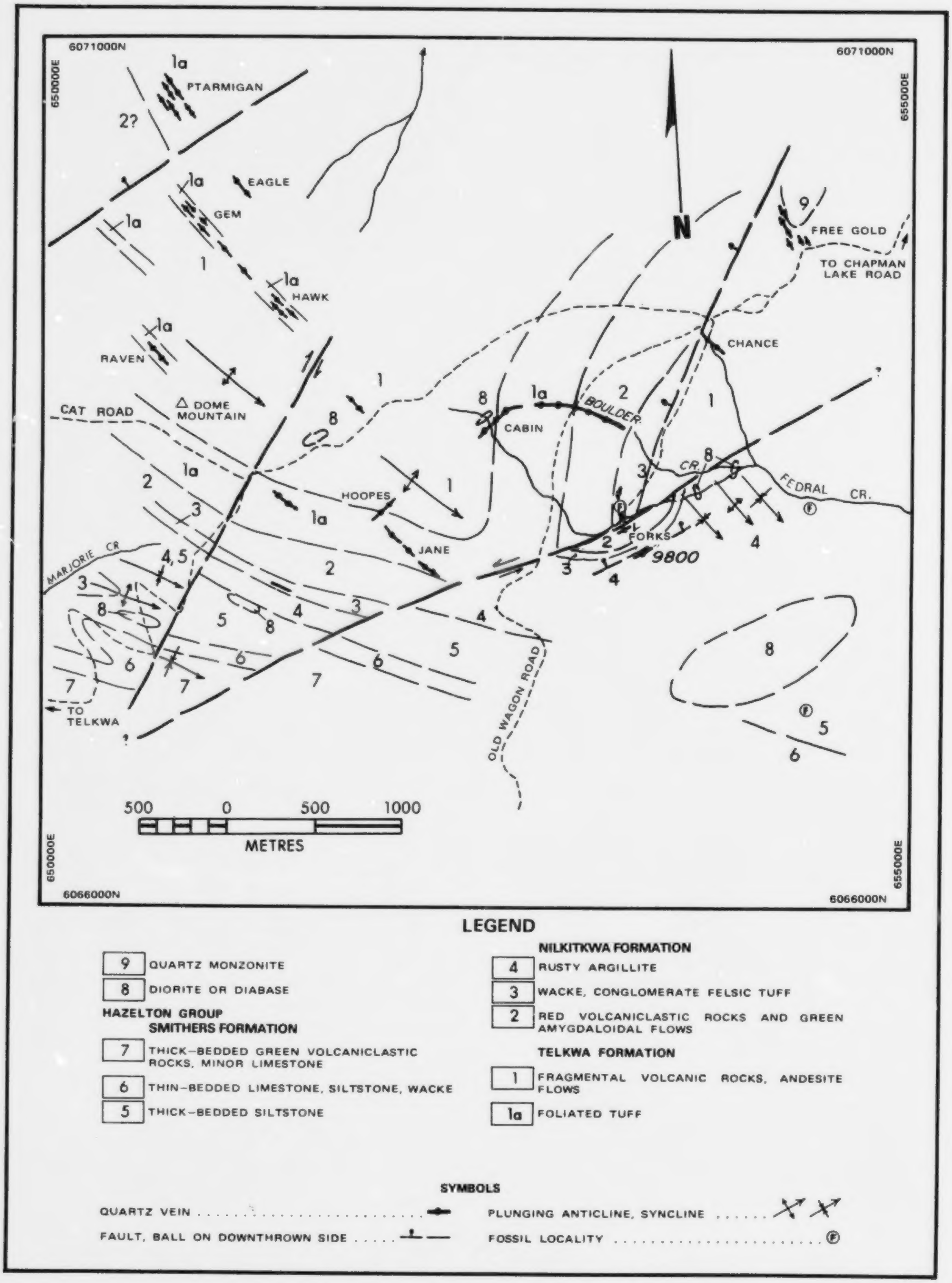

6071000N
650000E
655000E
6066000N
PTARMIGAN
EAGLE
GEM
HAWK
RAVEN
DOME MOUNTAIN
CAT ROAD
HOOPES
JANE
CABIN
BOULDER CR.
CHANCE
FREE GOLD
TO CHAPMAN LAKE ROAD
FEDRAL CR.
FORKS
9800
MARJORIE CR.
OLD WAGON ROAD
TO TELKWA
N
500 0 500 1000
METRES
LEGEND
9 QUARTZ MONZONITE
8 DIORITE OR DIABASE
HAZELTON GROUP
SMITHERS FORMATION
7 THICK-BEDDED GREEN VOLCANICLASTIC ROCKS, MINOR LIMESTONE
6 THIN-BEDDED LIMESTONE, SILTSTONE, WACKE
5 THICK-BEDDED SILTSTONE
NILKITKWA FORMATION
4 RUSTY ARGILLITE
3 WACKE, CONGLOMERATE FELSIC TUFF
2 RED VOLCANICLASTIC ROCKS AND GREEN AMYGDALOIDAL FLOWS
TELKWA FORMATION
1 FRAGMENTAL VOLCANIC ROCKS, ANDESITE FLOWS
1a FOLIATED TUFF
SYMBOLS
QUARTZ VEIN
FAULT, BALL ON DOWNTHROWN SIDE
PLUNGING ANTICLINE, SYNCLINE
FOSSIL LOCALITY

Figure 3-8-5. Geological sketch map of the Dome Mountain gold camp.

Recent Exploration Activity

During the 1984 field season all the properties on Dome Mountain, with the exception of the Free Gold, were under option to Noranda Exploration Ltd. In 1984 and 1985, Noranda soil sampled on a newly cut grid, built a road, and completed 68 trenches and 20 diamond-drill holes, mainly in the vicinity of the Forks deposit. The Hoopes, Cabin, and Hawk veins were also drill tested. In November 1985, Canadian United Minerals Inc., which has a 25 per cent carried interest in the project, became the operator and early in 1986, discovered a new vein near Boulder Creek by trenching a soil geochemical anomaly. Canadian United subsequently completed 48 drill holes on this vein, with encouraging results. The Boulder Creek vein is now the main exploration target on Dome Mountain.

An agreement has recently been completed between Canadian United Minerals Inc., Reako Explorations Ltd., Panther Mines Ltd., Noranda Exploration Ltd., Teeshin Resources Ltd. and Total Erickson Resources Ltd., whereby Total Erickson will become project manager and Canadian United will acquire a 100 per cent interest in the property (George Cross Newsletter, Number 207, October 28, 1986). Total Erickson will provide $6 million for 7 000 000 common shares of Canadian United. Of these funds, $2.9 million is to be spent on development of current reserves and a production feasibility study.

Vein Characteristics

Most of the veins on Dome Mountain trend northwest and dip steeply to the northeast or southwest; the Hoopes, Cabin and Boulder Creek veins trend northeast and may be part of the same vein system.

Several different stratigraphic units host the quartz veins. The most economically significant veins, the Forks and Boulder Creek, occur in the red epiclastic-amygdaloidal flow unit of the lower Nilkitkwa Formation. The Boulder Creek vein crosscuts this unit and probably extends into the phyllitic maroon tuff of the Telkwa Formation as it approaches the Cabin vein. The thin-bedded argillite unit of the Nilkitkwa Formation hosts the 9800 vein; all other veins on Dome Mountain occur in phyllitic tuff of the Telkwa Formation. These veins both parallel and crosscut the foliation. The Free Gold veins are an exception; they are hosted by massive andesite and a quartz-feldspar porphyry intrusion.

The quartz veins vary from a few centimetres up to 3 metres in width. Some veins are lenticular and locally folded and brecciated; others have considerable lateral continuity with little variation in attitude and do not appear to be deformed.

A lime green mica is common within the most intensely altered zones. Originally believed to be fuchsite or mariposite, it has now been identified by the Geological Survey Branch analytical laboratory as a green variety of sericite.

Boulder Creek — Cabin Vein

The Boulder Creek vein strikes east and dips 50 to 60 degrees south. Surface exposures are restricted to a series of trenches across the vein (Figure 3-8-6). Canadian United dug these trenches because of moderately anomalous zinc concentrations in two adjacent soil samples. Drilling has subsequently defined a quartz-carbonate vein containing sphalerite, galena and minor chalcopyrite, within a zone of strong sericitic wallrock alteration, that extends at least 400 metres along strike and persists to a vertical depth greater than 140 metres. The vein cuts diagonally across amygdaloidal flows and foliated tuff of the Nilkitkwa Formation (lJN1). The best intersection is 16.5 metres of 17 grams/tonne (54 feet of 0.49 ounces/ton) gold. Canadian United Minerals has calculated a geological reserve of 240, 000 tons (218 000 tonnes) grading 0.458 ounces/ton (15.57 grams/tonne) gold and 2.32 ounces/ton (78.88 grams/tonne) silver (Don Harrison, personal communication). It is likely that the Boulder Creek vein is the same as the Cabin vein which is located 350 metres on strike to the west. Thus the vein is likely to exceed 750 metres in length.

Noranda has completed ore microscopy studies of samples from the Boulder Creek vein. Relatively coarse gold occurs on sulphide boundaries and as microveinlets within sulphide grains; moderate grinding should liberate most of this gold.

The Cabin vein outcrops near the headwaters of Fedral Creek, where it is approximately 3 metres wide and strikes northeast. The quartz-carbonate vein contains abundant pyrite with lesser galena, sphalerite, chalcopyrite and arsenopyrite. Gold values are reported to be relatively low (Minister of Mines Annual Report, 1922). The vein crosscuts the foliation in a narrow zone of strongly altered and foliated rock that bounds the vein. The history of underground exploration at the Cabin vein is described more fully in a previous report (MacIntyre, 1985).

The Geological Survey Branch analytical laboratory has completed analyses on seven grab samples from the Cabin vein (Table 3-8-2). The maximum gold value was 12.3 grams/tonne.

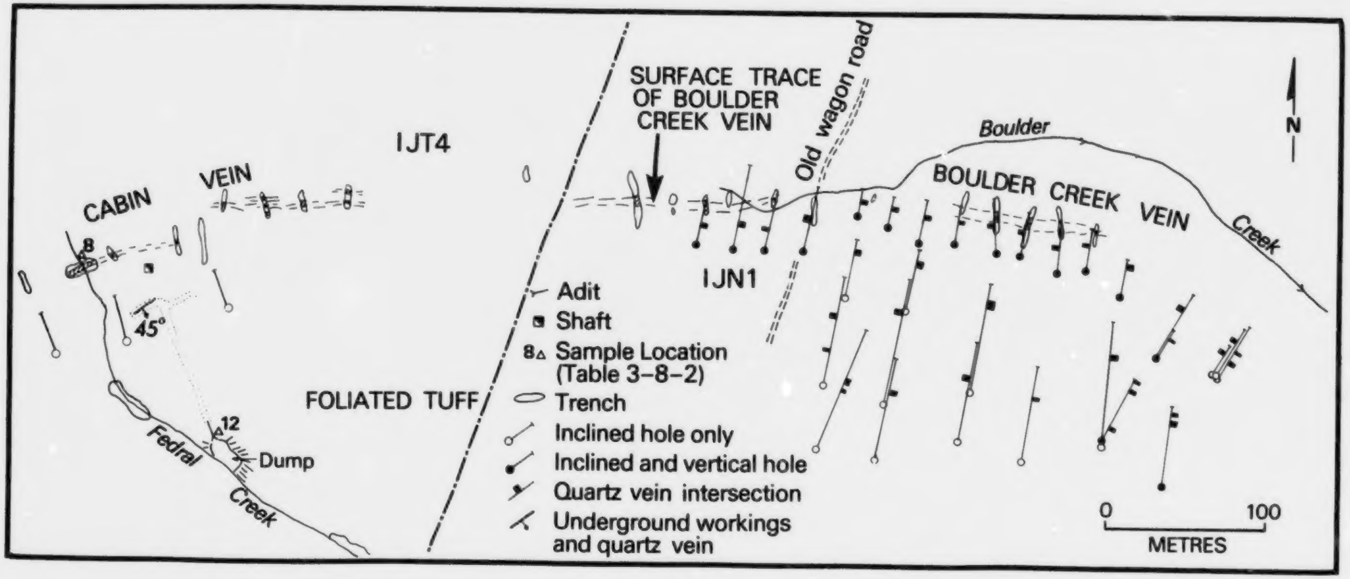
Forks Vein (Mineral Inventory 093L-022)

The history of the Forks showing and a description of the underground workings are contained in a previous report (MacIntyre, 1985). Stream deposits now cover the original showing, which is reported to occur in the bed of Fedral Creek, just below its confluence with a small southern tributary (Minister of Mines Annual Reports, 1922, 1923, 1924). Outcrops on the banks of the creek, above and below the showing, are pervasively sericite-carbonate-altered foliated tuffs with quartz stringers (Figure 3-8-7). These rocks are at the transition from amygdaloidal flows to marine sedimentary rocks within the lower Nilkitkwa stratigraphic succession. Several short adits were driven into this zone in the early days of exploration but did not cut any major quartz veins. However, subsequent underground development by the Dome Mountain Min-

TABLE 3-8-2 — CABIN VEIN ANALYSES
(all values in ppm)

No.	Au	Ag	Cu	Pb	Zn	Co	Ni	Mo	Cd	Hg	As	Sb	Ba
8	5.5	126	8000	48800	24200	2	14	4	410	7.0	1700	1400	68
8A	8.2	77	4000	28300	22700	2	14	6	380	4.8	887	566	34
8B	4.1	157	6800	4200	4900	14	12	12	78	0.4	154	68	50
8C	7.5	370	34600	3800	13400	8	10	<4	255	1.9	1700	2800	135
8D	<0.3	<10	320	110	540	12	<2	<4	6	0.1	20	26	1920
12	12.3	106	19000	3300	6700	6	11	4	124	8.4	850	1400	139
12A	<0.3	<10	142	40	255	16	3	<4	<1	<.1	52	<5	1102

8, 8A, 8B, 8C = quartz vein, outcrop in creek; 8D = sericite altered volcanic adjacent to vein; 12 = quartz vein, Cabin vein adit dump; 12A = altered volcanic, Cabin vein adit dump



SURFACE TRACE OF BOULDER CREEK VEIN
Old wagon road
Boulder
Creek
N
CABIN VEIN
IJT4
IJN1
BOULDER CREEK VEIN
8
45°
12
Dump
Fedral
Creek
FOLIATED TUFF
Adit
Shaft
8▵ Sample Location (Table 3-8-2)
Trench
Inclined hole only
Inclined and vertical hole
Quartz vein intersection
Underground workings and quartz vein
0
100
METRES

Figure 3-8-6. Geological sketch map and drill hole plan, the Cabin-Boulder Creek zone.

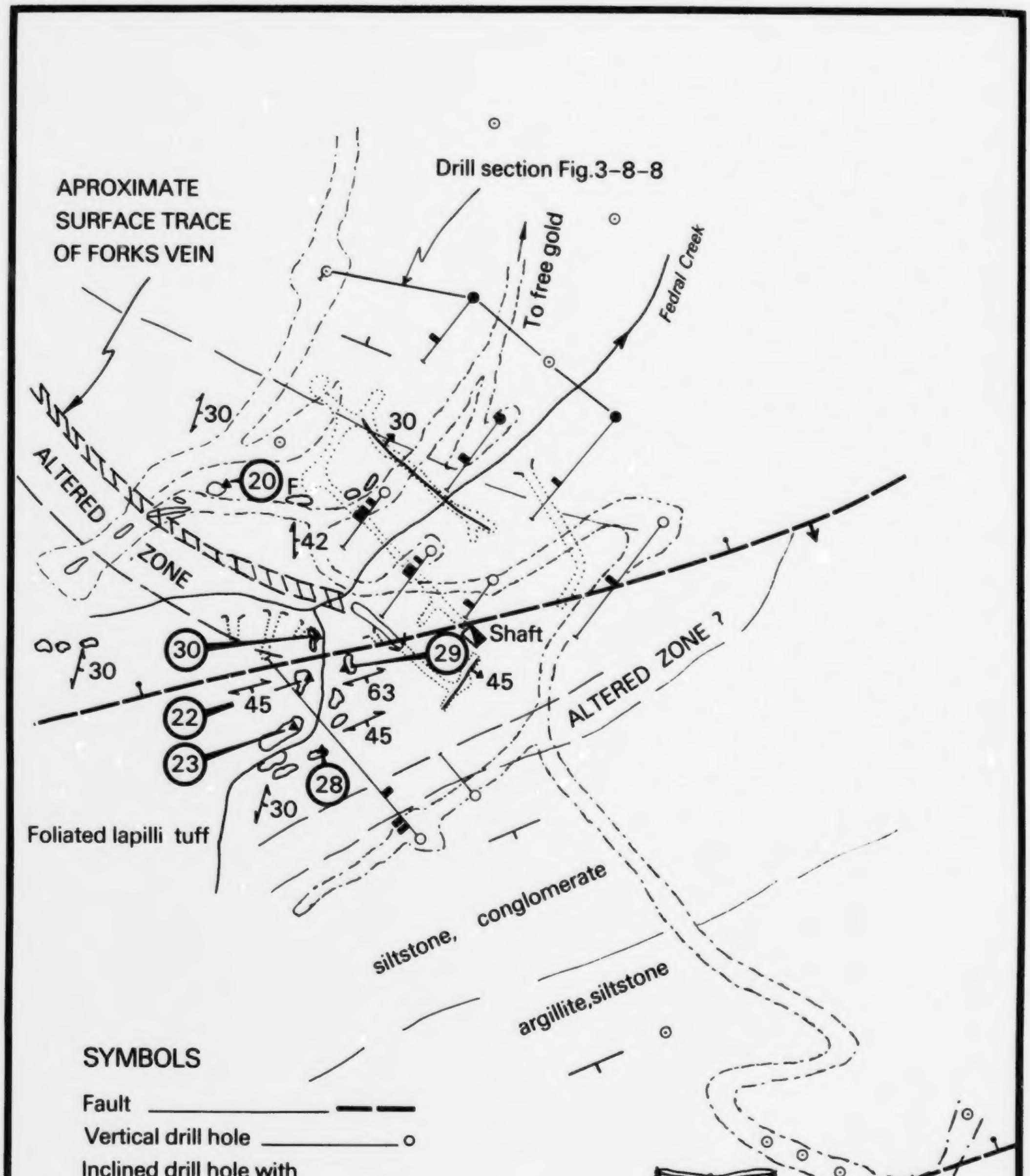

APROXIMATE
SURFACE TRACE
OF FORKS VEIN
Drill section Fig.3-8-8
To free gold
Fedral Creek
30
30
42
30
45
63
45
45
30
20
F
30
22
23
28
29
Shaft
ALTERED ZONE
ALTERED ZONE ?
Foliated lapilli tuff
siltstone, conglomerate
argillite,siltstone
SYMBOLS
Fault
Vertical drill hole
Inclined drill hole with mineralized section
Underground workings with quartz vein
Foliation trend
Trench
Outcrop
Surface sample see table 3-8-3
9800 SHOWING
0
50
metres
SEE FIGURE 3-8-2 FOR MAP SYMBOL LEGEND

Figure 3-8-7. Geological sketch and drill hole plan, Forks area.

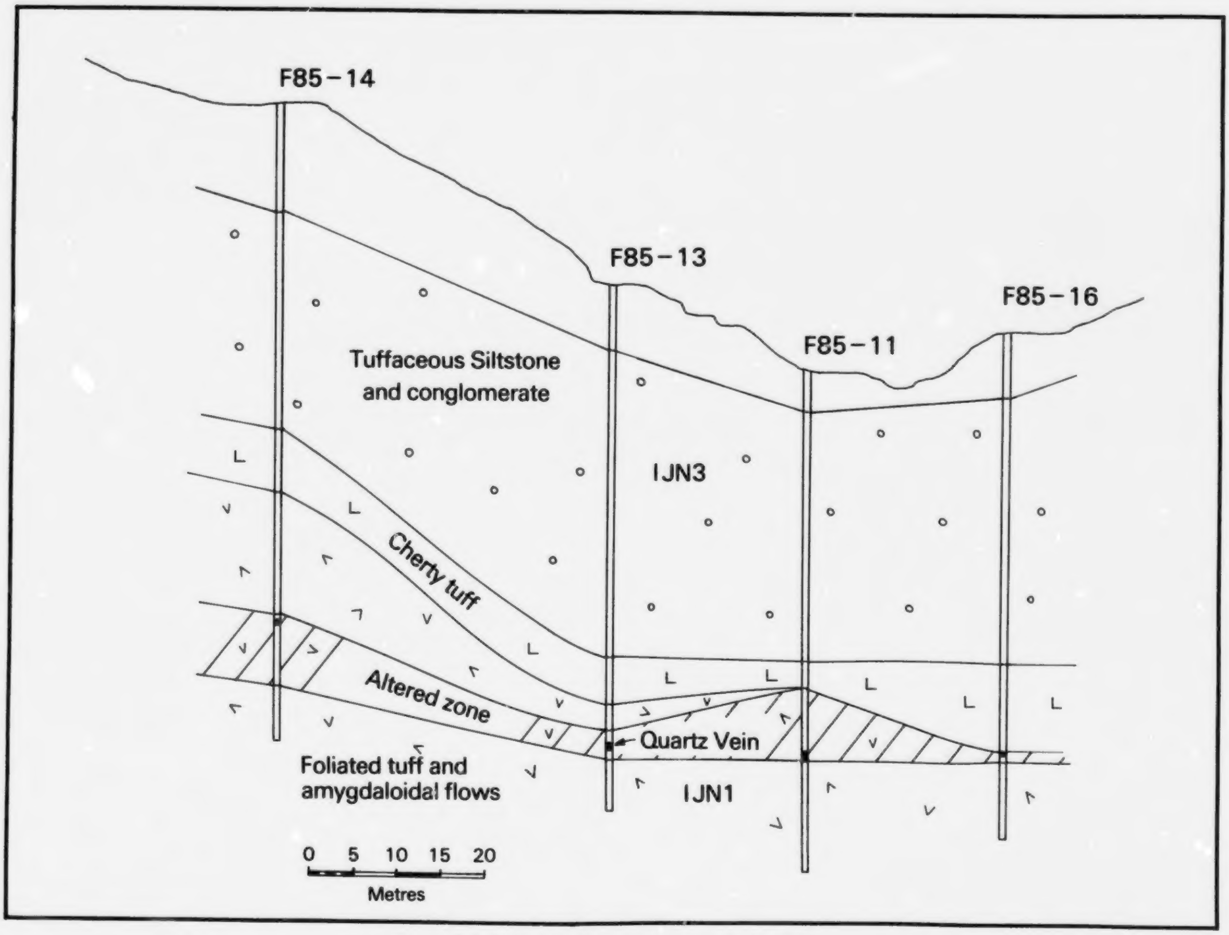


Figure 3-8-8. Drill hole cross section, Forks vein.

ing Company in 1923 and 1924 did intersect two major veins, one trending northwest and dipping northeast, the other trending northeast and dipping southeast (Figure 3-8-7). Our interpretation is that these veins are the same and are offset and rotated by a fault.

In 1985 Noranda drilled 16 holes to test the down-dip extension of the Forks vein (Figure 3-8-7). This work has defined a geological reserve of 20 000 tonnes grading 23.6 grams/tonne (0.688 ounce/ton) gold (Don Harrison, personal communication). Examination of drill core indicates that the quartz vein and enclosing sericite alteration zone, which varies in thickness from hole to hole, cuts across bedding at a low angle (Figure 3-8-8) and is near the top of the amygdaloidal flow unit of the Nilkitkwa Formation.

The Geological Survey Branch analytical laboratory has completed analyses on three grab samples from the Forks vein (1, 1A, 1B in Table 3-8-3) and ten grab samples of sericite-altered volcanic rock adjacent to the vein (1C to 30A in Table 3-8-3). In general zinc values are greater than lead and copper, gold and silver values increase with increasing zinc and lead in the vein and arsenic, antimony, mercury and cadmium concentrations are anomalous. Altered wallrocks have anomalous concentrations of zinc and barium.

9800 Vein

Trenching of a coincident soil geochemical anomaly and mineralized float occurrence led to the discovery of the 9800 or Baseline occurrence in 1985. Vertical drill holes collared north of the showing intersected narrow quartz-carbonate veins with relatively low gold and silver values. These veins occur at a similar stratigraphic position to that of the Forks. Subsequent trenching of the showing has exposed spectacular high-grade mineralization which may have some continuity to the south.

During August 1986, M. Lavesseur directed a small-scale mining operation. A three-man crew drilled, blasted and hand-sorted high-grade material from an open trench. Several tonnes were milled near Smithers then shipped to the Trail smelter.

Mineralization at 9800 zone is a discordant vein which cuts stratigraphy and cleavage. Mineralization occurs as: (1) foliated to massive sphalerite-galena-pyrite-chalcopyrite layers and lenses; and (2) white quartz veins and stringers with disseminated pyrite, sphalerite, and galena. Quartz and massive sulphide vein contacts with host rock shale and grey tuff are sharp.

Hangingwall alteration is limited to minor quartz veining extending less than 20 centimetres into the overlying black shale. The footwall is veined by folded and contorted white quartz stringers (stockwork). The host grey tuff is bleached and contains disseminated arsenopyrite needles, scorodite and pyrite. Sphalerite, galena, and pyrite veins and patches occur locally. The stockwork zone is cut by anastamosing shear planes.

The north edge of the workings shows the vein at the shale-tuff contact; to the south the vein lies within grey tuff. The tuff slaty cleavage is at a high angle to the vein, perhaps near a fold closure.

TABLE 3-8-3. FORKS VEIN ANALYSES

(all values in ppm)

No.	Au	Ag	Cu	Pb	Zn	Co	Ni	Mo	Cd	Hg	As	Sb	Ba
1	27.4	134	3000	8800	47600	12	17	8	855	19	1200	550	161
1A	17.5	52	2600	1200	63000	13	39	92	858	18	1500	288	143
1B	65.5	474	8000	63700	89000	20	22	6	150	24	2100	2500	66
1C	<0.3	<10	103	30	780	28	83	4	9	0.3	30	7	409
18	<0.3	<10	87	36	118	33	63	<4	<1	0.1	100	<5	649
20	<0.3	<10	73	16	92	12	6	6	<1	0.1	10	<5	425
22	<0.3	<10	27	12	118	19	45	<4	<1	0.1	64	<5	689
22A	<0.3	<10	65	52	546	16	55	<4	6	0.1	50	<5	655
23	<0.3	<10	29	18	70	15	45	<4	<1	<.1	<10	<5	1112
28	<0.3	<10	28	18	92	16	49	<4	<1	0.4	42	<5	1090
29	<0.3	<10	62	42	1300	18	43	<4	9	1.0	38	5	592
30	<0.3	<10	112	196	6700	19	52	4	65	6.9	148	<5	254
30A	<0.3	<10	102	18	450	13	36	<4	4	1.3	74	6	443

1, 1A, 1B, 1C = quartz vein with pyrite, sphalerite, galena and minor chalcopyrite, from dump at Forks shaft; 20 = altered volcanic wacke, hangingwall, Forks vein; 18, 22, 23, 28, 29, 30A sericite-altered volcanic, footwall, Forks vein; 22A = barren quartz vein in sericite-altered footwall; 30 = quartz-carbonate vein, sericite-altered footwall.

TABLE 3-8-4. 9800 ZONE ANALYSES

(all values in ppm)

No.	Au	Ag	Cu	Pb	Zn	Mo	Hg	As
254-1	42.93	196	1100	1500	19500	<5	2.15	79000
254-2	2.64	49	435	1500	16300	<5	1.64	20000
254-3	0.17	13	71	1100	1500	38	0.16	350
254-4	76.61	1809	7000	147000	298000	<5	11.36	18000
254-5	10.43	519	1800	8400	17700	<5	1.60	44000

254-1 = quartz vein with minor sphalerite, arsenopyrite from trench, 9800 zone; 254-2, 254-3 = veined and altered host rock from trench; 254-4, 254-5 semimassive sulphide in quartz vein from trench.

TABLE 3-8-5. MOUNT MCKENDRICK VEIN ANALYSES

(all values in ppm)

	Au	Ag	Cu	Zn	Mo	Hg	As	Sb
23-1	3.03	123	470	13100	4	2.15	960	335
23-3	1.09	78	600	30400	<2	2.54	13600	170

23-1, 23-3 = quartz vein with pyrite, minor sphalerite, Mount McKendrick showing.

Our interpretation is that a fault with downward displacement to the north separates the 9800 showing from the area drilled by Noranda and that the vein dips to the south, away from the fault. Mineralogically, the 9800 vein is similar to the Forks and it may be an offset segment of this vein system.

The Geological Survey Branch analytical laboratory has analysed five grab samples from the 9800 vein. The results are given in Table 3-8-4. One sample of semimassive sulphide contained 76.62 grams/tonne gold, 1809 grams/tonne silver, 29.8 per cent zinc, 14.7 per cent lead, 1.80 per cent arsenic, 0.70 per cent copper.

Mt. McKendrick (Pioneer) (Mineral Inventory 093L-266)

A northwest-trending, steeply northeast-dipping quartz vein cuts the greenstone-granitic sill complex and overlying Telkwa Formation phyllitic tuffs on the south slope of Mount McKendrick. The vein extends for 500 metres and ranges up to 0.9 metre wide. John McKendrick first discovered the vein in the early 1900s and staked the St. Anne and St. Eugene claims. He subsequently completed a 16-metre exploratory adit which has now collapsed. The vein is described in the Minister of Mines Annual Report for 1934.

The Geological Survey Branch analytical laboratory has analysed two grab samples from the Mount McKendrick vein. The results are given in Table 3-8-5. The samples contain minor amounts of sphalerite and arsenopyrite. Mercury concentrations are also anomalous.

Genetic Model

Two possible genetic models for the gold-silver quartz veins of the Babine Range are: (1) the veins are related to buried intrusives that were emplaced during the early stages of folding; or (2) the veins were produced by fluids generated during folding and metamorphism of a thick volcanic pile.

The first hypothesis is favoured because of the strong aeromagnetic anomaly associated with Dome Mountain (Figure 3-8-9). This anomaly suggests that a buried intrusive occupies the core of the mountain. This postulated intrusive may be dioritic in composition, as indicated by several small plugs and dykes that crop out south of the Forks deposit. Quartz veins cut the quartz-feldspar porphyry exposed at the Free Gold, indicating this intrusion predates mineralization.

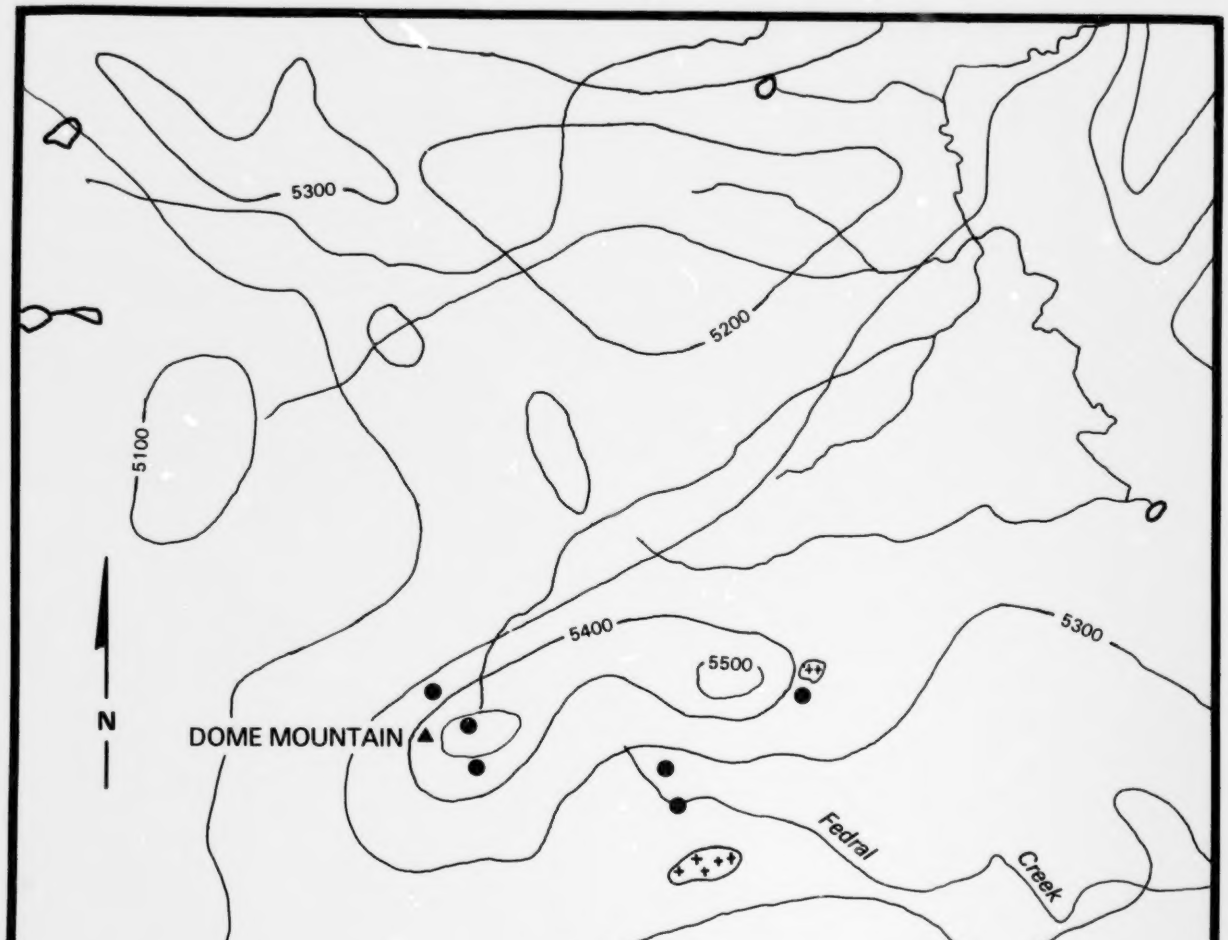

5300
5200
5100
5400
5500
5300
N
DOME MOUNTAIN
Fedral Creek
5200
DECEPTION LAKE
Guess Creek
0
5
Kilometres

Figure 3-8-9. Relationship of mineral occurrences to aeromagnetic anomalies.

Sericitic wallrock alteration is most intense near the Forks, Boulder Creek and Cabin veins. These veins, which are zinc and lead-rich, occur at a higher stratigraphic level than copper-rich veins that lack wallrock alteration. This suggests a zoning model similar to that shown in Figure 3-8-10 may be applicable to the Dome Mountain camp.

Sulphide mineralogy is also variable. Observed sulphide mineral assemblages include pyrite, pyrite-chalcopyrite, pyrite-chalcopyrite-galena, pyrite-galena-sphalerite-chalcopyrite and pyrite-arsenopyrite-sphalerite-galena. As shown in Figure 3-8-10, veins with copper greater than zinc and lead are interpreted to be deeper and closer to the heat source as in the classic mesothermal vein model. Reactivity with wallrock increases away from the heat source as the temperature differential between rock and fluid increases and the fluid boiling point is reached.

The age of mineralization is not well established. However, many of the quartz veins are folded and broken suggesting the veining predates or is contemporaneous with deformation. The timing of folding and uplift is probably post-Albian, pre-Late Cretaceous. The mesothermal veins in the Dome Mountain camp may be of this age. The Geological Survey Branch is currently processing samples of sericite alteration from the Forks vein for potassium-argon isotopic age dating.

COPPER-SILVER VEINS

Camp Lake

Amygdaloidal basalt of the Nilkitkwa Formation hosts several copper-silver vein occurrences. The veins are small and discontinuous. They typically occur in zones of pervasive chlorite-epidote-carbonate alteration. The Camp Lake occurrence is typical of this type of mineralization. D. Groot Logging Limited of Smithers completed one drill hole on the prospect in 1982 but failed to intersect mineralization at depth.

Tina

In lower Byron Creek, on the Tina property, a narrow shear zone with irregular patches of malachite, azurite, chalcopyrite and tetrahedrite-tennantite (X-ray diffraction identification by Dr. John Kwong, Geological Survey Branch analytical laboratory) cuts massive rhyolite of the Nilkitkwa Formation. Several barren, 5 to 10-centimetre quartz-carbonate veins also occur along shear planes up-stream from the showing. The Geological Survey Branch analytical laboratory has completed analyses on several grab samples from these veins (Table 3-8-6) but no significant gold or silver values were detected.

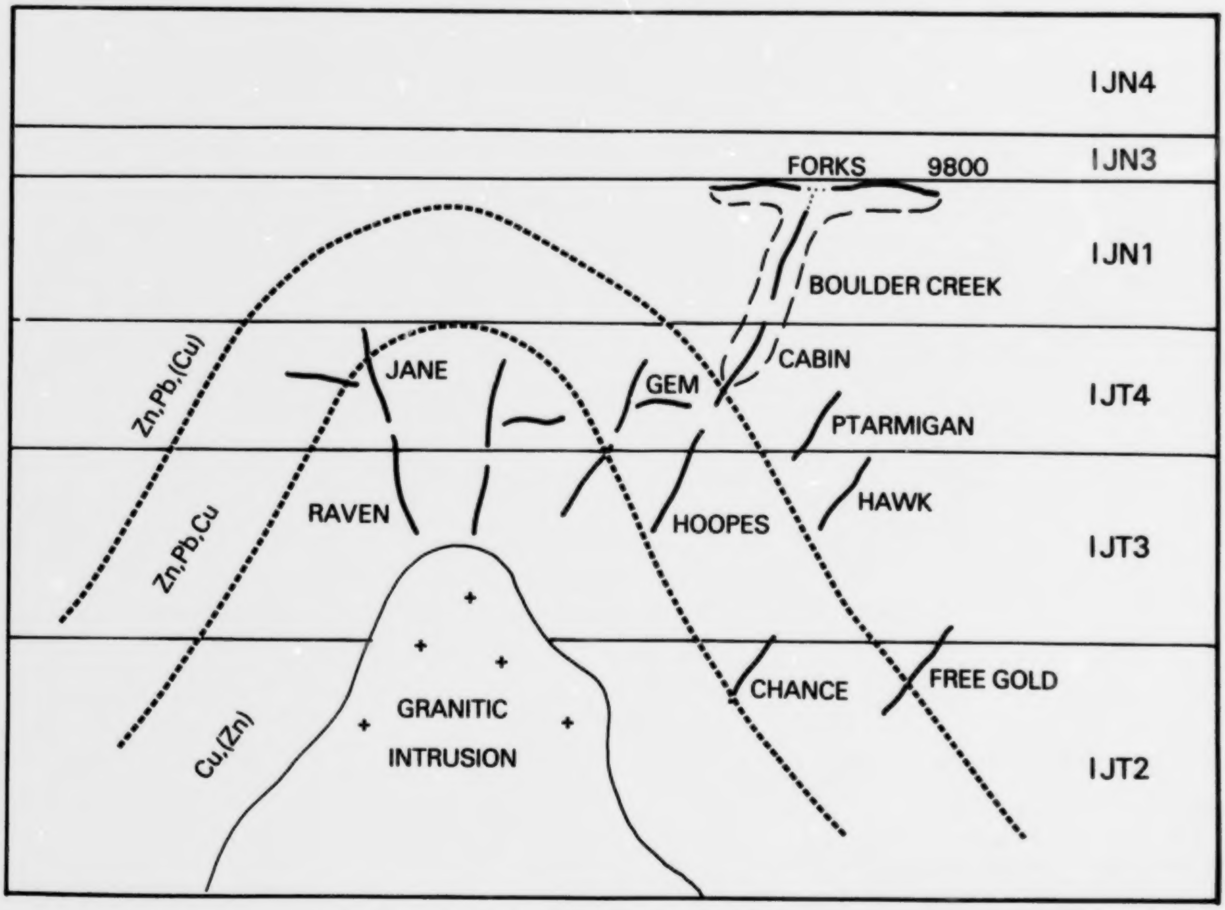


Figure 3-8-10. Genetic model, Dome Mountain camp.

TABLE 3-8-6. TINA COPPER PROSPECT ANALYSES
(all values in ppm)

	Au	Ag	Cu	Zn	Mo	Hg	As	Sb
49-1	<0.017	<10	18	200	9	0.06	<20	<10
50-3	<0.017	<10	18	200	9	0.06	<20	<10
50-5	0.020	<10	27	136	3	0.04	<20	<10
55-3	<0.017	<10	6	46	5	0.02	<20	<10
50-6	<0.020	<10	5500	1200	13	18.00	4900	743

49-1 = altered volcanic, Byron Creek; 50-3, 50-5, 50-6, 55-3 = narrow, barren quartz vein in shear zones, Tina prospect, Byron Creek.

Brenda/Tony (Mineral Inventory 093L-142, 143)

Alex Chisholm originally staked the Tony property as the Ivanhoe Group. In 1928 and 1929, T. Blythman optioned the property from Chisholm and completed a 3-metre shaft. In 1968, John Bot of Smithers staked the Tony claims. Dome Babine Mines Limited subsequently optioned the property and completed airborne magnetometer and electromagnetic surveys.

The main exploration target is a northeast-trending, southeast-dipping shear zone up to 2 metres wide, cutting steeply dipping to vertical andesite on the crest of a small hill. Tetrahedrite and minor chalcopyrite occur within the shear zone. Silver values are reported to be less than 70 grams/tonne. A granitic intrusion of probable Jurassic age crops out approximately 400 metres west of the shaft. The intrusion is cut by small quartz veins containing chalcopyrite.

CUPROUS MASSIVE SULPHIDE DEPOSITS

Del Santo (Mineral Inventory 093L-025)

The Del Santo prospect is located near the headwaters of Deep Creek. The showing was originally called Deep Creek and is described in the 1929 Minister or Mines Annual Report. The showing was restaked by Mel Chapman and Frances Madigan in the mid 1960s. Texas Gulf Sulphur Co., Falconbridge Limited, Bovan Mines Ltd., Midwest Oil Ltd., Union Miniere and Petra Gem Exploration of Canada Ltd. have all explored the property.

The main showing is a north-trending band of massive pyrrhotite, chalcopyrite and minor sphalerite that apparently overlies east-dipping chlorite-epidote altered amygdaloidal andesite or basalt (lJN1). The sulphide band, which appears to occupy a fold closure, has been exposed by trenching over a strike length of 50 metres. Overlying the massive sulphides are thin-bedded shaly siltstones and argillaceous limestones that are probably part of the Nilkitkwa Formation. East of the showing, these rocks are overlain by tuffaceous sandstones of the Smithers Formation. A biotite granodiorite crops out southeast of the showing and has been dated at 47.1 ± 1.6 Ma (unpublished date, The University of British Columbia geochronology laboratory).

The Geological Survey Branch analytical laboratory has completed analyses on three grab samples of massive sulphide from the Del Santo property. Results are given in Table 3-8-7. The massive sulphide is rich in silver and has relatively low lead and zinc concentrations.

POLYMETALLIC MASSIVE SULPHIDE

Ascot

The Ascot property is located between Mount McKendrick and Dome Mountain. The area was staked by Texas Gulf in 1967 because of anomalous silt geochemistry. Early work involved soil geochemistry, airborne magnetic and electromagnetic surveys, ground electromagnetic surveys and geologic mapping (Peatfield and Loudon, 1968) all directed toward a massive sulphide target. Several small massive pyrite lenses with minor amounts of sphalerite, galena and barite were found in limy siltstones and felsic tuff of the Nilkitkwa Formation, close to the contact with underlying amygdaloidal basalt. In 1972, Texas Gulf drilled three short packsack holes near the Canyon Creek showings to test electromagnetic conductors, but intersected only disseminated sphalerite and galena in a limy tuffaceous siltstone. The claims were dropped in 1977 and the area restaked as the MS claims by Kevin Coswan of Smithers. Between 1977 and 1979, the property was under option to Petra Gem Exploration of Canada Ltd. and from 1979 to 1984 Rapitan Resources Inc. and Barry Price held the claims. Geostar Mining Corp. acquired the ground in 1984.

The main showing on the property is 400 metres up Canyon Creek from the old Texas Gulf camp, where thin bands of light-coloured sphalerite with specks of galena and tetrahedrite occur in a limy siltstone. Farther up-stream barite, sphalerite, chalcopyrite and arsenopyrite occur at the fault contact between amygdaloidal flows and limy sedimentary rocks of the Nilkitkwa Formation. Several similar faults cross Canyon Creek and juxtapose amygdaloidal flows against tuffaceous conglomerates and limy siltstones.

In Canyon Creek, southeast of the old Texas Gulf campsite, a bed of coarse recrystallized pyrite occurs in a limy siltstone that apparently overlies thin-bedded, highly contorted Nilkitkwa argillite. No other sulphides were observed at this locality.

In 1969, Texas Gulf drilled one hole near the headwaters of Canyon Creek that intersected limy siltstone and possibly felsic tuff of the Nilkitkwa Formation. The hole tested an area of anomalous soil geochemistry and apparently intersected 15 metres of fine-grained felsic tuff or siltstone containing pyrite, sphalerite and galena as disseminations and filling hairline fractures. A diorite sill intrudes thin-bedded argillites that overlie the mineralized section.

Analyses of samples from the Ascot property are given in Table 3-8-8. The samples are altered siltstone or felsic tuff that contain disseminated pyrite, galena and sphalerite. No significant gold or silver values were detected.

PORPHYRY COPPER-MOLYBDENUM DEPOSITS

Burbridge Lake (Summit) (Mineral Inventory 093L-223)

The Burbridge Lake property is accessible via Woodmere road, which joins Highway 16 approximately 1.6 kilometres south of the town of Telkwa, and thence via 11.3 kilometres of rough forest access road.

The property was first explored as the Paradise Group (Minister of Mines Annual Report, 1919) and later as the Bulkley Group (Minister of Mines Annual Report, 1929). Prospectors completed several open cuts and at least one short adit on a northwest-striking, southwest-dipping zone up to 15 metres wide and 175 metres long, cutting altered rhyolitic tuffs of the Nilkitkwa Formation. Mineralization within this zone consists of semimassive pyrite and magnetite with minor sphalerite and chalcopyrite in a quartz gangue. As far as is known the mineral zone does not contain significant gold or silver concentrations.

TABLE 3-8-7. DEL SANTO ANALYSES
(all values in ppm)

	Au	Ag	Cu	Pb	Zn	Mo	Hg	As	Sb
127-1	<0.02	239	5200	480	2100	<5	4.50	68	3000
127-2	0.02	562	11600	262	3100	<5	15.00	155	6600
129-1	0.04	106	15200	45	475	<5	2.20	93	22

All samples massive pyrrhotite with minor chalcopyrite from trenches on main showing.

TABLE 3-8-8. ASCOT PROPERTY ANALYSES
(all values in ppm)

	Au	Ag	Cu	Pb	Zn	Mo	Hg	As	Sb
61-A	0.05	<10	41		2600	6	0.11	<20	<10
61-B	<0.03	<10	67		107	13	<0.02	<20	<10
63-1	0.10	<10	17		23	4	0.02	1400	<10
64-2	0.03	<10	48		91	5	<0.02	0	<10
68-1	<0.02	<10	52	56000	1100	<5	18.60	<25	<5

61-A, 61-0 = B altered siltstone, near showing below old Texas Gulf camp, Canyon Creek; 63-1, 64-2 = altered siltstone near packsack drill holes, upstream from old camp, Canyon Creek; 64-2 = altered siltstone, Canyon Creek; 68-1 = altered siltstone with disseminated galena in shear zone at contact between amygdaloidal flows and altered siltstone, Canyon Creek.

In 1969, Mel Chapman of Smithers restaked the Burbridge Lake property after discovering copper mineralization adjacent to a foliated diorite intrusion. In 1973 Hudson's Bay Oil and Gas Company Ltd. completed 366 metres of diamond-drilling in three holes. One hole intersected 49 metres of 0.3 per cent copper. In 1974, Cities Service Limited optioned the property and completed 495 metres of drilling in two holes, but did not intersect any significant mineralization.

In 1976, Asarco Exploration Company of Canada Ltd., recognizing that earlier drilling was parallel to the regional foliation and therefore parallel to the contact of the diorite, optioned the property and completed 649 metres of drilling in six holes (MacIntyre, 1977). This work confirmed that the diorite was a sill dipping moderately to the southwest. The upper part of the sill is porphyritic, approaches granodiorite to quartz monzonite in composition and is pervasively altered to clay, chlorite, carbonate, sericite and quartz with disseminated and fracture-controlled pyrite, chalcopyrite and molybdenite mineralization. A zone of disseminated and banded pyrite extends into altered rhyolitic volcanic rocks above the contact. The best copper and molybdenum grades occur at the transition from argillic to propylitic alteration, which corresponds to a change from porphyritic quartz monzonite to foliated diorite.

In 1980 and 1981, D. Groot Logging Limited of Smithers, completed 941 metres of diamond drilling in eight holes. This work showed that the diorite sill is cut off by a fault to the west and that limy sedimentary strata overlie the altered felsic to andesitic volcanic rocks south of the sill.

Big Onion (Mineral Inventory 093L-124)

A prominent gossan is exposed on the south slope of Astlais Mountain. This area was first staked as the Cimbria group in the early 1920s. In 1927 the property was owned by A. Elmstead. Under his direction, several adits were driven into the mineralized zone. In 1963 and 1964, Noranda Exploration Ltd. mapped and sampled the property and subsequently completed 76 metres of drilling in two holes. Between 1965 and 1967 Texas Gulf Sulphur Co. completed an additional 765 metres of diamond drilling in five holes. In 1970, Blue Rock Mining Corp. Ltd. completed additional mapping, and geochemical and geophysical surveys. Between 1975 and 1976, Canadian Superior Exploration Limited drilled 7174 metres in 18 diamond and 66 percussion holes. This work defined a mineral inventory of 18 million tonnes grading 0.36 per cent copper (Canadian Institute of Mining and Metallurgy, Special Volume 15, Table 1 in pocket, showing No. 73).

The Big Onion prospect has been described by Sutherland Brown (1966) and Carter (1981). Mineralization is associated with an irregular, northeast-trending stock of quartz feldspar porphyry, with an altered core of porphyritic quartz diorite, that intrudes Telkwa and Nilkitkwa Formation rocks. A zone of disseminated pyrite, chalcopyrite and molybdenite mineralization occurs within the altered phase. As mentioned earlier, a sample of intense sericite alteration has given an isotopic age of 117 Ma and a post-mineral quartz monzonite porphyry dyke was dated at 48.7 Ma (Carter, 1981).

CONCLUSIONS

The Nilkitkwa Formation, as defined in this report, is an important host to mineral deposits in the Babine Range. With the exception of a few small quartz veins on Dome Mountain, all of the mineral deposits examined in this study occur within a relatively narrow stratigraphic interval of the Nilkitkwa Formation. The most important veins on Dome Mountain, the Boulder Creek and Forks, occur in the amygdaloidal flow unit or overlying sedimentary rocks. Stratabound cuprous and polymetallic massive sulphide deposits, such as Del Santo and the Ascot showings, occur in sedimentary strata immediately overlying the amygdaloidal flow or rhyolitic volcanic units. The amygdaloidal flow unit also hosts copper-silver veins such as the Tony and Camp Lake. The Burbridge Lake porphyry deposit occurs at the transition from amygdaloidal flows to rhyolitic volcanic rocks.

The Nilkitkwa Formation is obviously a favourable host for mineral deposits and is an important metallotect in the Babine Range for both syngenetic and epigenetic mineralization. The transition zone from bimodal volcanism, as represented by the amygdaloidal flow and rhyolitic volcanic units, to a marine sedimentary environment should be a prime exploration target in the area, especially for volcanogenic massive sulphide deposits.

Mesothermal precious metal veins are probably related to buried granitic intrusions. The Nilkitkwa volcanic rocks are a favourable host for these vein deposits.

ACKNOWLEDGMENTS

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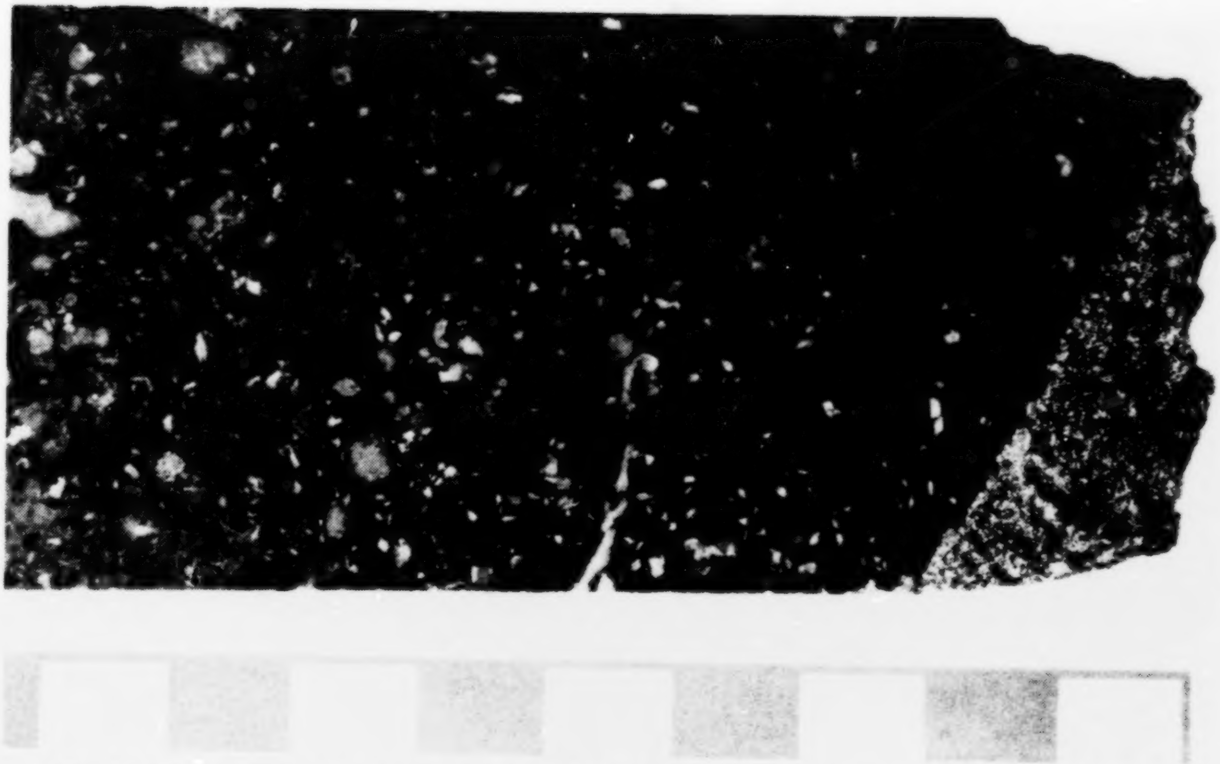

Plate 3-8-1. Typical sample of amygdaloidal phyric basalt, unit lJN1. Dark patches are chlorite. Drill core from Forks deposit.

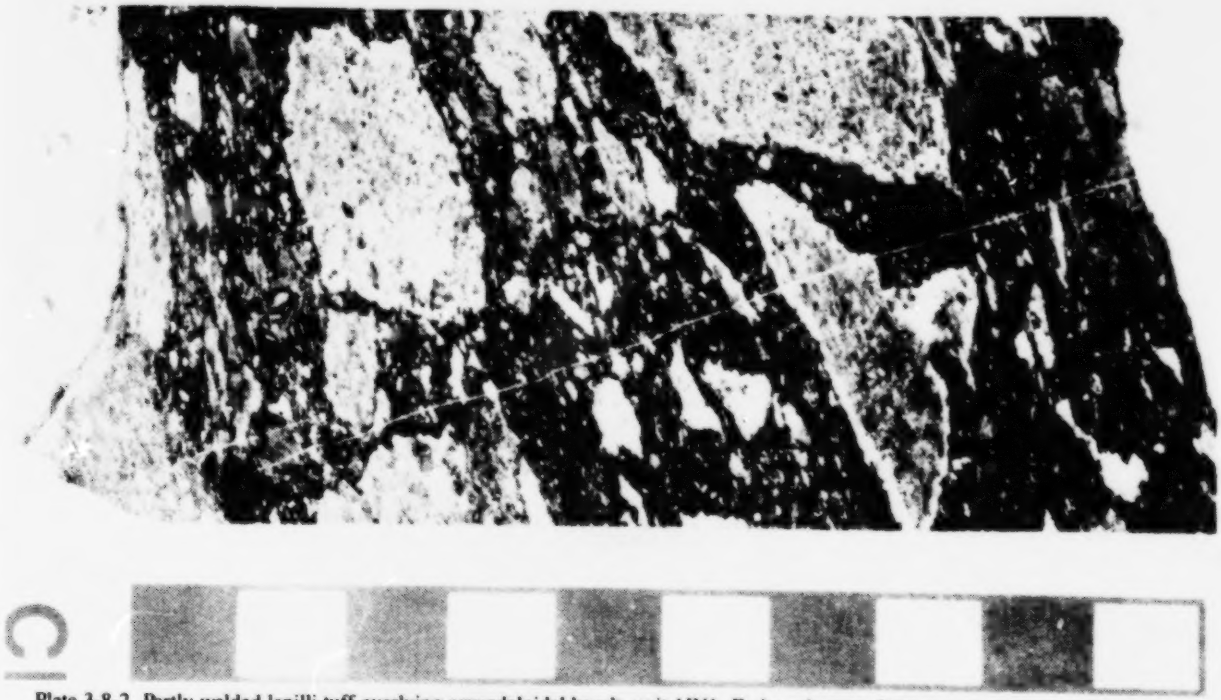

Plate 3-8-2. Partly welded lapilli tuff overlying amygdaloidal basalt, unit lJN1. Forks vein area. Note reaction rims on angular felsic clasts.

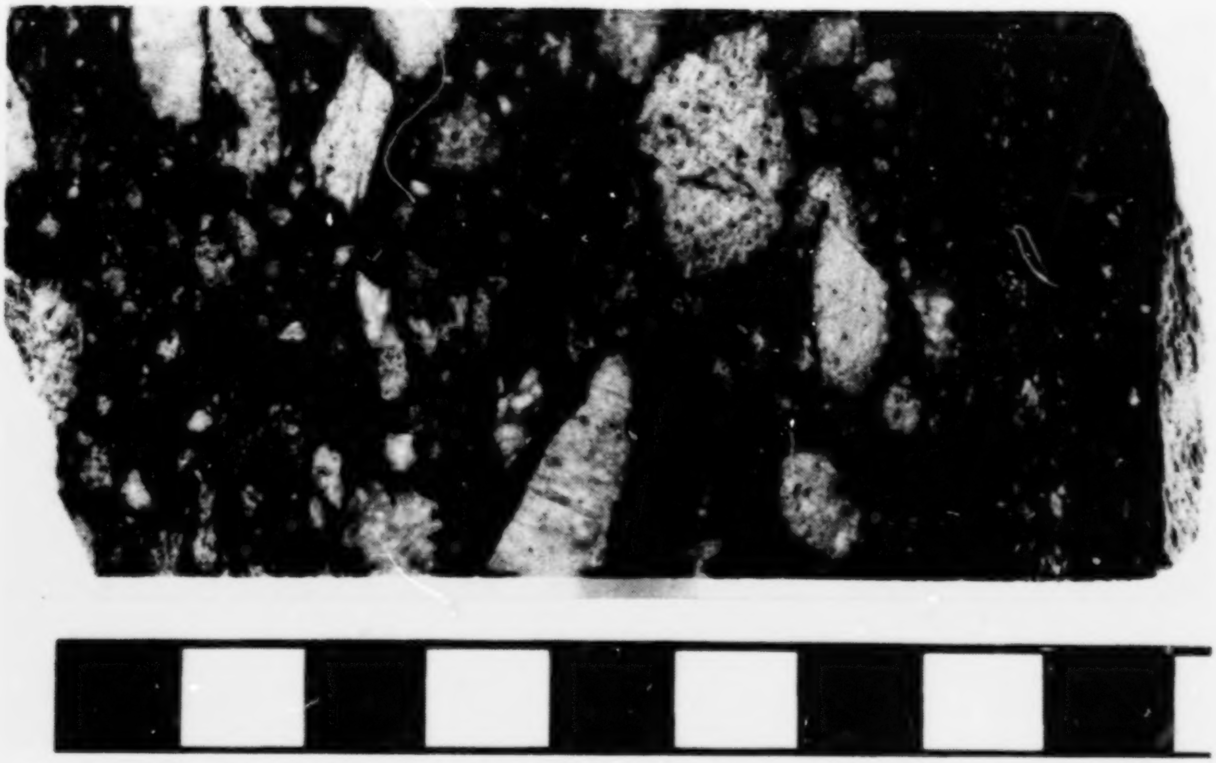

Plate 3-8-3. Pebble conglomerate with subangular clasts of rhyolite and dacite in tuffaceous, sandy matrix, unit 1JN3. Drill core from Forks deposit.

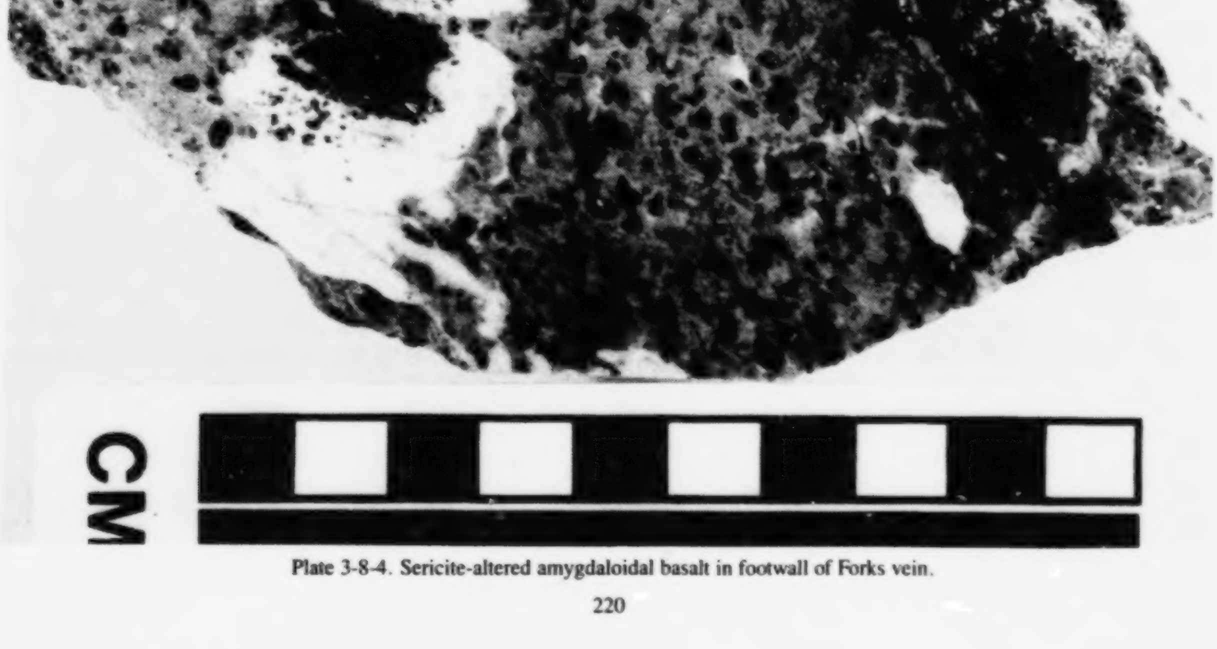

Plate 3-8-4. Sericite-altered amygdaloidal basalt in footwall of Forks vein.

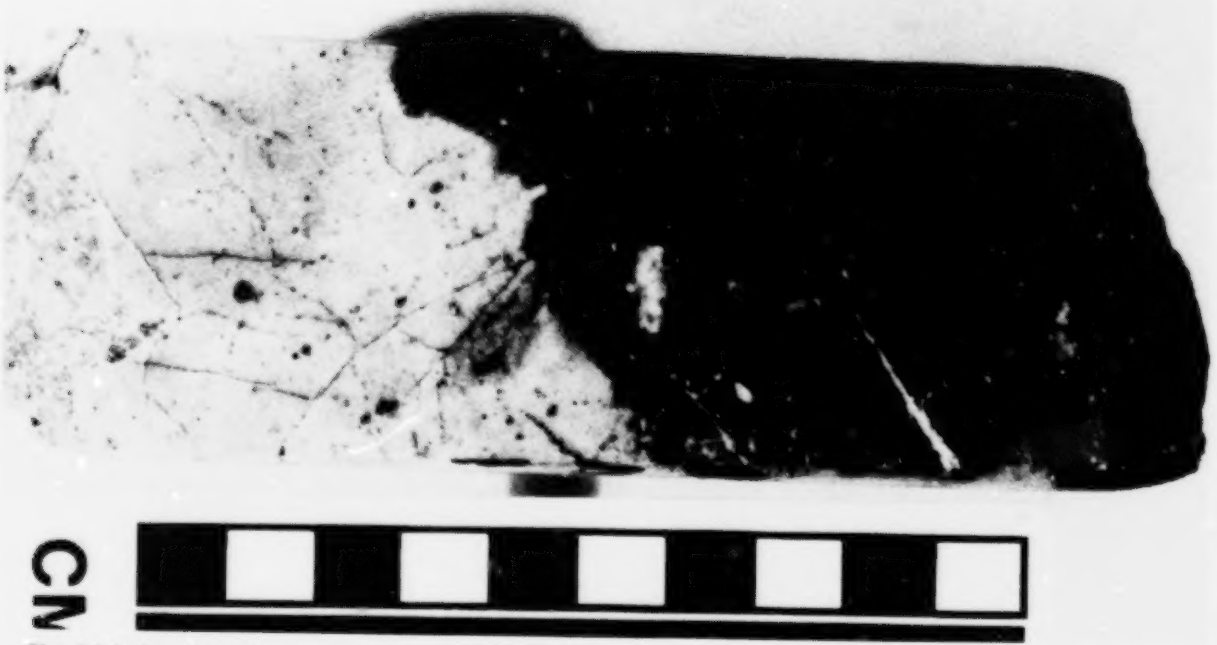

Plate 3-8-5. Granule conglomerate in hangingwall of Forks vein showing transition into pervasive sericite alteration (bleached part of sample).

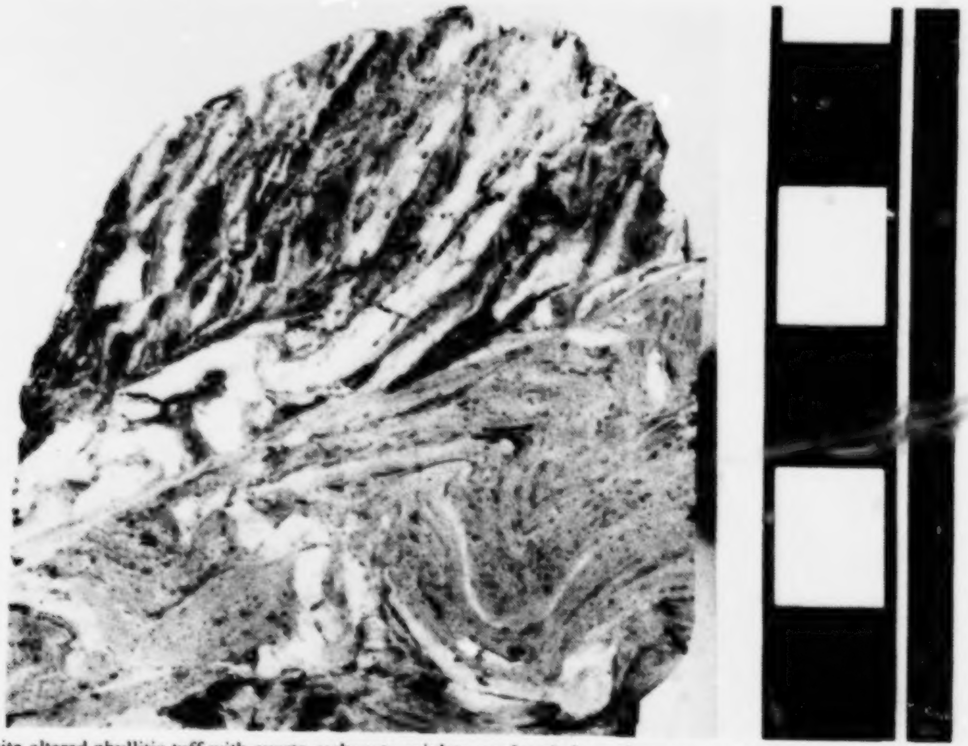

Plate 3-8-6. Sericite-altered phyllitic tuff with quartz-carbonate veinlets emplaced along cleavage planes. Note folding of slaty cleavage and quartz veinlets and offset along microfault.

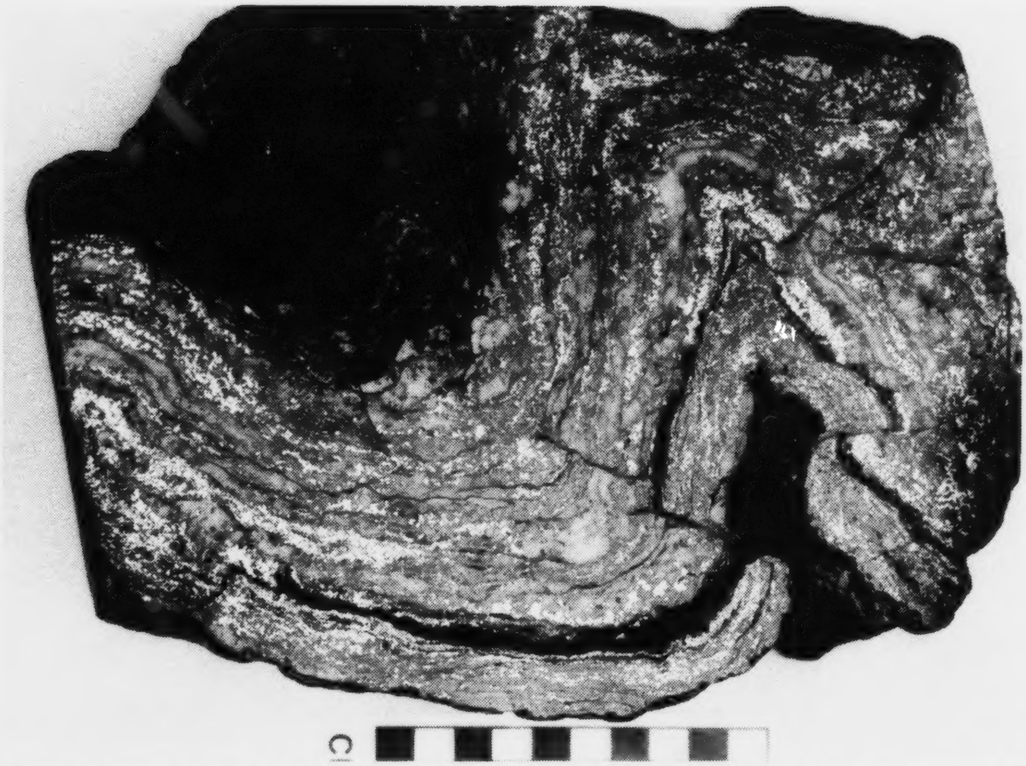

Plate 3-8-7. Folded quartz vein with bands of broken pyrite and chalcopyrite grains. Sample is from the Raven vein adit.

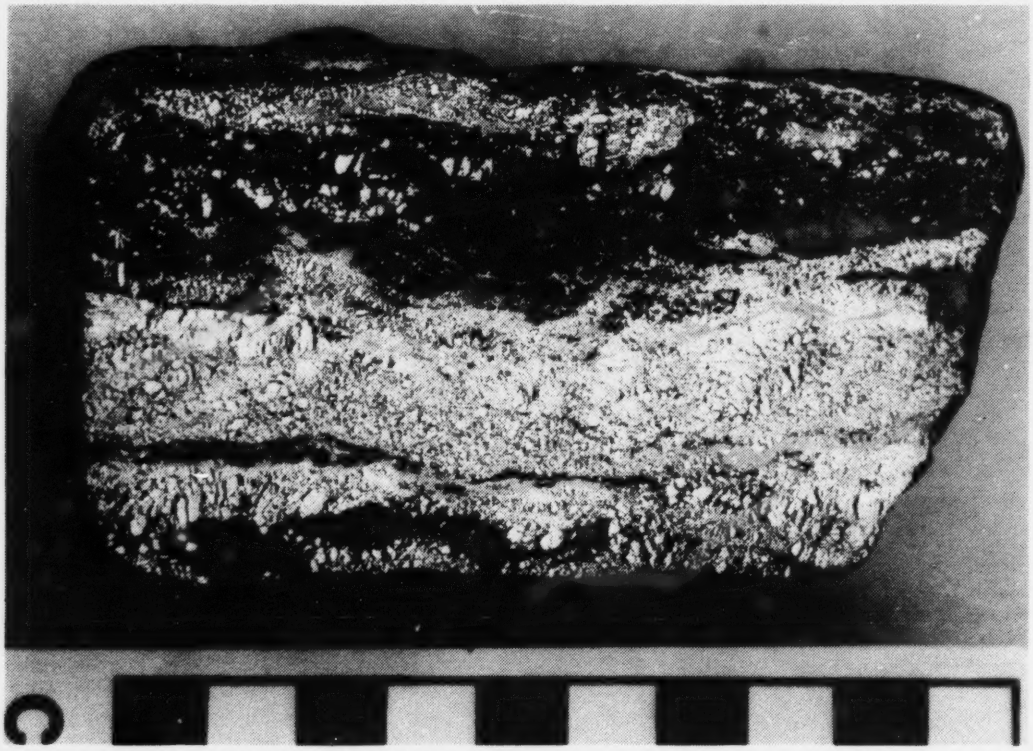

Plate 3-8-8. Quartz vein with semi-massive pyrite, sphalerite and galena bands. Note broken nature of sulphides. Sample is from the new 9800 showing.

GEOLOGY OF THE COWICHAN LAKE AREA, VANCOUVER ISLAND*

(92C/16)

By N. W. D. Massey and S. J. Friday

INTRODUCTION

The Paleozoic Sicker Group of Vancouver Island is host to several types of mineral deposits including polymetallic Kuroko-type massive sulphides such as Westmin Resource Ltd.'s Buttle Lake deposits. Much recent exploration activity has been concentrated in the Horne Lake-Cowichan uplift. With the initiation of 1:50 000 regional mapping by the Geological Survey Branch under the Canada/British Columbia Mineral Development Agreement, this area was selected for more detailed analysis than presently available. During the 1986 field season fieldwork was centred on the Cowichan Lake area (Figures 3-9-1 and 3-9-2). Access in the area is provided by an extensive network of logging roads in various states of upkeep. Roadcuts provide most of the exposure for mapping; rock units are poorly exposed under the thick forest cover or along creeks.

PREVIOUS WORK

The Sicker Group was first defined by Clapp (Clapp, 1912; Clapp and Cooke, 1917) as the Mount Sicker Series, although erroneously interpreted as younger than the Karmutsen Formation (Vancouver Series). Gunning (1931) recognized that the volcanics of the Sicker Group in the Buttle Lake area were older than the basalts of the Karmutsen Formation. This relationship was confirmed in the Cowichan Lake area by Fyles (1955), who also recognized the Buttle Lake limestone as the uppermost unit in the Sicker Group. Yole (1963, 1965, 1969), though principally concerned with the limestones, redefined the internal stratigraphy of the Sicker Group and made the first formal correlations between the Horne Lake-Cowichan and Buttle Lake uplifts. Muller and colleagues (Muller, 1982, 1985; Muller and Carson, 1968; Muller, Northcote and Carlisle, 1974) have extended mapping to all areas of Vancouver Island, formalizing stratigraphic nomenclature for Paleozoic (Sicker Group) and Mesozoic (Vancouver and Bonanza Groups) sequences. Detailed investigations of small areas around Duncan have been reported on by Eastwood (1979, 1980, 1982) and 1:50 000-scale mapping in the Alberni-Bamfield corridor was undertaken by the Geological Survey of Canada in support of the LITHOPROBE 1 Project (Sutherland Brown *et al.*, 1986). Biostratigraphic and radiometric dating of the rocks of southern Vancouver Island has been summarized by Muller and Jeletzky (1970), Brandon *et al.* (1986), and Armstrong *et al.* (unpublished preprint).

REGIONAL SETTING

The Cowichan Lake area lies on the southern flank of the Horne Lake-Cowichan uplift, one of a series of major geanticlines that make up the structural fabric of southern Vancouver Island (Figure 3-9-1). The area is underlain by all the formations typical of Wrangellia (Sicker Group, Vancouver Group and Bonanza Group) and its successor basin (Nanaimo Group). It lies between the two main study areas of the LITHOPROBE 1 Project.

STRATIGRAPHY

The oldest rocks in the Cowichan Lake area belong to the Paleozoic Sicker Group (Figure 3-9-3), which contains volcanic and sedimentary units ranging from Late Silurian to Early Permian in age. These are intruded by mafic sills, and overlain unconformably by basaltic volcanics of the Late Triassic Karmutsen Formation. Succeeding limestones, argillites and tuffaceous sediments of the Quatsino and Parson Bay Formations (which with the Karmutsen Formation make up the Vancouver Group) are conformably to disconformably overlain by marine sediments and marine to subaerial volcanics of the Early to Middle Jurassic Bonanza Group. All of these sequences have been intruded by granodioritic stocks of the Middle Jurassic Island intrusions. Late Cretaceous sediments of the Nanaimo Group lie unconformably on the older sequences.

SICKER GROUP

Since the initial definition of the Sicker Group by Clapp (1912), there have been several attempts at subdivision into formations. The most recent was that by Muller (1980), who proposed four subdivisions. In ascending stratigraphic order they are the Nitinat Formation, the Myra Formation, an informal sediment-sill unit, and the Buttle Lake Formation. Recent paleontological and radiochronological studies (Brandon *et al.*, 1986), coupled with newer mapping (Sutherland Brown *et al.*, 1986; Sutherland Brown and Yorath, 1985), has thrown some doubt on these subdivisions and their applicability in the Horne Lake-Cowichan uplift. Division is also hampered by the lack of significant, laterally continuous marker units, making correlation between fault slices often impossible. Consequently, formal stratigraphic subdivisions are avoided in this project for the time being. The thickness of the Sicker Group, or any of its constituent parts, is very difficult to determine due to repetition by folding and faulting, but must be at least 1500 metres.

Within the Cowichan Lake area, the lowermost unit in the Sicker Group is a volcanic package characterized by pyroxene-feldspar porphyritic agglomerates, breccias, lapilli tuffs and crystal tuffs. Pyroxenes are large, up to 3 centimetres diameter, euhedral to subhedral, and vary from 5 to 20 per cent of the rock. Plagioclase is equally abundant, but phenocrysts are usually smaller, ranging up to 1 centimetre. Clasts in coarser pyroclastics are frequently amygdaloidal with chlorite, quartz or calcite infillings. Pillowed and massive flows are also found, both aphyric and porphyritic. Minor laminated tuff and tuffaceous sandstone are present locally. This volcanic unit is probably equivalent to the Nitinat Formation of Muller (1980).

The volcanic unit is overlain, apparently conformably, by a sequence of volcaniclastic sediments and minor volcanic rocks. A variety of lithologies are developed including thickly bedded, massive tuffaceous sandstones and lithic sandstones with interbedded laminated sandstone-siltstone-argillite. Breccias and lapilli tuffs are usually heterolithic and include aphyric and porphyritic lithologies, commonly mafic to intermediate in composition, though some minor felsic tuffs were observed. Pyroxene-bearing breccias may be

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

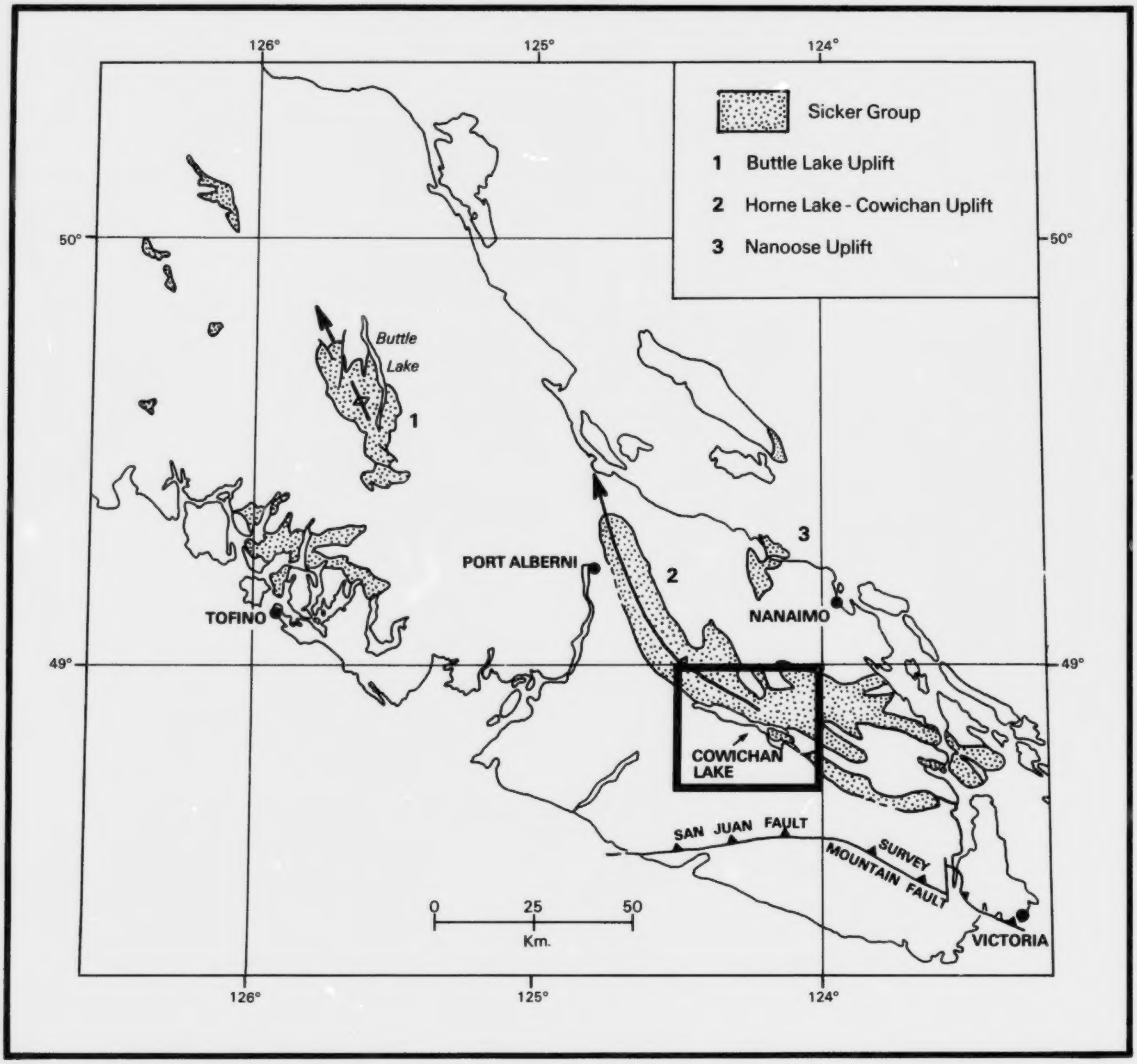


Figure 3-9-1. Location of the Cowichan Lake area, southern Vancouver Island, in relation to the three major geanticlinal uplifts cored by Sicker Group rocks (after Brandon *et al.*, 1986).

interbedded with tuffaceous sandstone in the lower part of the sequence, forming a transition zone into the underlying volcanics.

The upper part of the Sicker Group is made up of a dominantly epiclastic sedimentary package. This unit is often found directly in faulted or, more commonly, unconformable contact with the volcanics. The base of the sedimentary unit is marked by a 100 to 200-metre-thick sequence of ribbon cherts, laminated cherts and cherty tuffs that constitutes the only marker horizon in the area. It passes upwards into thinly bedded, turbiditic sandstone-siltstone-argillite intercalations. Thicker beds of sandstone, granule sandstone, breccia and conglomerate are also found, containing clasts of cherty material, volcanic-derived lithic clasts and feldspar and pyroxene crystals. Crinoidal calcarenite and calcirudite with chert clasts and interbeds occur in the Mount Franklin area as a fault-bounded block. They are overlain by thinly bedded cherty sediments. Similar bioclastic calcarenites, with porcellaneous micrite and tuffaceous limestone interbeds, also occur on the north side of Bald Mountain and Marble Bay where they form the top of the Sicker Group, and are directly overlain by Karmutsen Formation basalts. These limestone units are the equivalents of the Buttle Lake limestone of Muller (1980) and other authors.

VANCOUVER GROUP

KARMUTSEN FORMATION

The Karmutsen Formation consists essentially of basaltic flows that typically weather orange-brown. They generally form rounded bluffs and hills. Pillowed and massive flows occur interbedded, though there is a tendency for massive flows to be dominant toward the top of the formation and pillowed flows in lower parts.

Hyaloclastite, hyaloclastite breccia and pillowed breccia occur within pillowed sections, and may also be interbedded with massive flows. Lithologically the flows are dark grey, variably feldsparphyric basalts. Feldspars are typically clumped and rarely single crystals. Coarser, glomeroporphyritic "daisy-flows" and hyaloclastite breccia are commonly seen at the top of the pile. Nearly all flows are amygdaloidal. The total thickness of the Karmutsen Formation in the area is difficult to estimate but is believed to be at least 2500 metres.

North of Cowichan Lake, a number of thick, massive, medium to coarse-grained diabase and gabbro sills intrude the Sicker Group sediments. They are equigranular to porphyritic, with feldspar phenocrysts often being glomeroporphyritic. These mafic intrusives are probably equivalent in age to the Karmutsen Formation volcanics that occur mainly to the south of the lake.

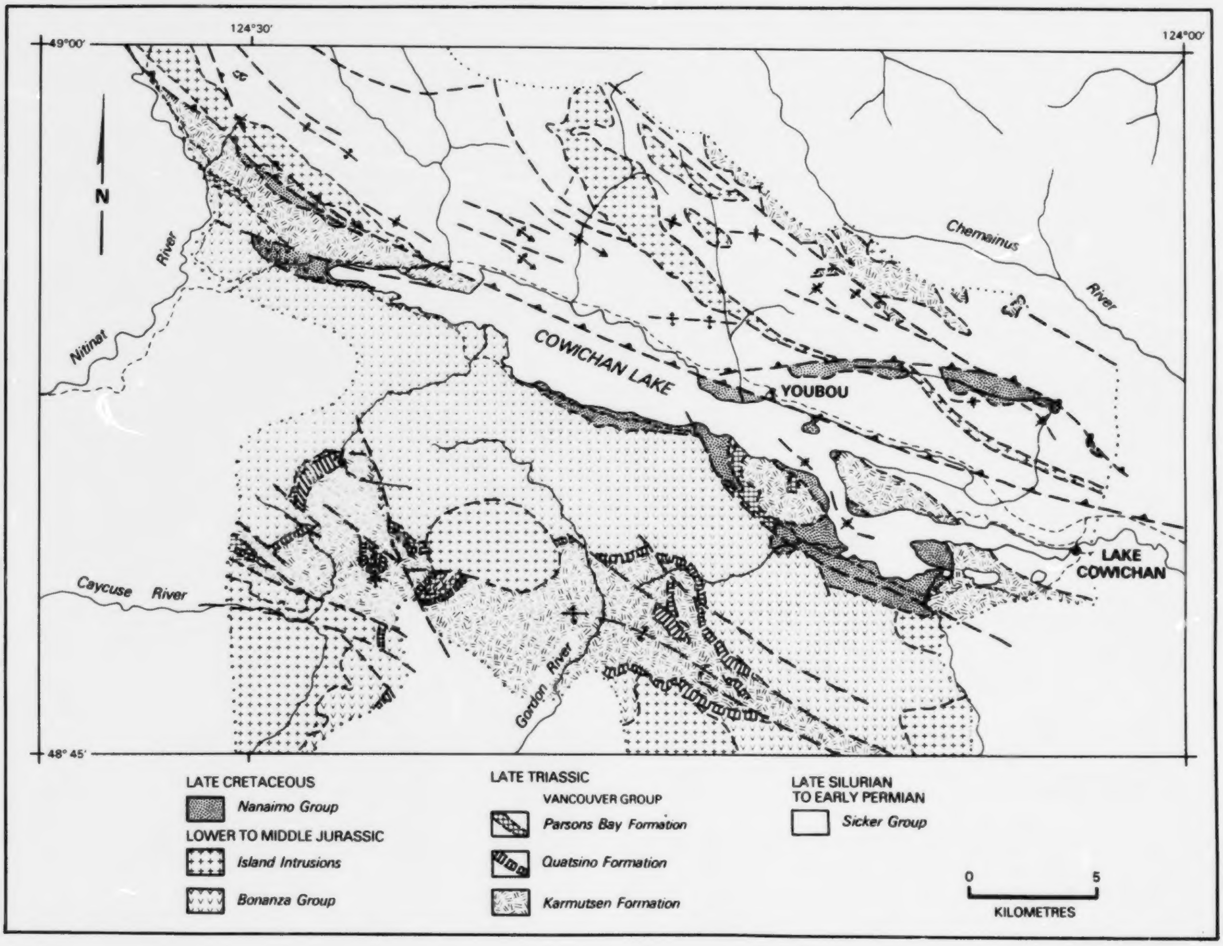
QUATSINO FORMATION

The Quatsino Formation is characterized by massive, thickly bedded, micritic limestone. It is fine grained, black in colour and often cut by a dense network of white sparry calcite veins. Weathered surfaces are grey and rough in texture due to secondary silica. Karst landforms are well developed. The micritic limestone is essentially unfossiliferous, but bioclastic micrite, oolitic limestone, calcirudite and calcarenite may occur locally.

The contact between the Karmutsen and the Quatsino Formations is often transitional with micritic limestones interbedded with massive flows and hyaloclastite breccias containing limestone clasts. A distinctive brick-red tuffaceous breccia or tuffaceous sandstone underlies the lowermost limestone in the Caycuse area. The Quatsino Formation is estimated to be no more than 75 metres thick, averaging 25 to 40 metres. It may be absent in some areas.

PARSON BAY FORMATION

In the Caycuse area the Quatsino Formation is immediately overlain, apparently conformably, by a 35-metre-thick sequence of thinly bedded sediments provisionally correlated with the Parson Bay Formation. The lowermost unit is a pale grey to maroon tuff and tuffaceous sandstone. It is overlain by flaggy limestone and limy argillites, with abundant ammonite, gastropod and pelecypod remains. This unit grades vertically into thinly bedded argillites with minor fossiliferous limestone interbeds. Maroon tuffs with flaggy sandy limestone and biohermal limestone ascribed to the Parson Bay Formation (Sutton Limestone Member) are also found on the



124°30′
124°00′
49°00′
48° 45′
N
Nitinat River
COWICHAN LAKE
YOUBOU
Chemainus River
LAKE COWICHAN
Caycuse River
Gordon River
LATE CRETACEOUS
Nanaimo Group
LOWER TO MIDDLE JURASSIC
Island Intrusions
Bonanza Group
LATE TRIASSIC
VANCOUVER GROUP
Parsons Bay Formation
Quatsino Formation
Karmutsen Formation
LATE SILURIAN TO EARLY PERMIAN
Sicker Group
0
5
KILOMETRES

Figure 3-9-2. Geology and structure of the Cowichan Lake area.

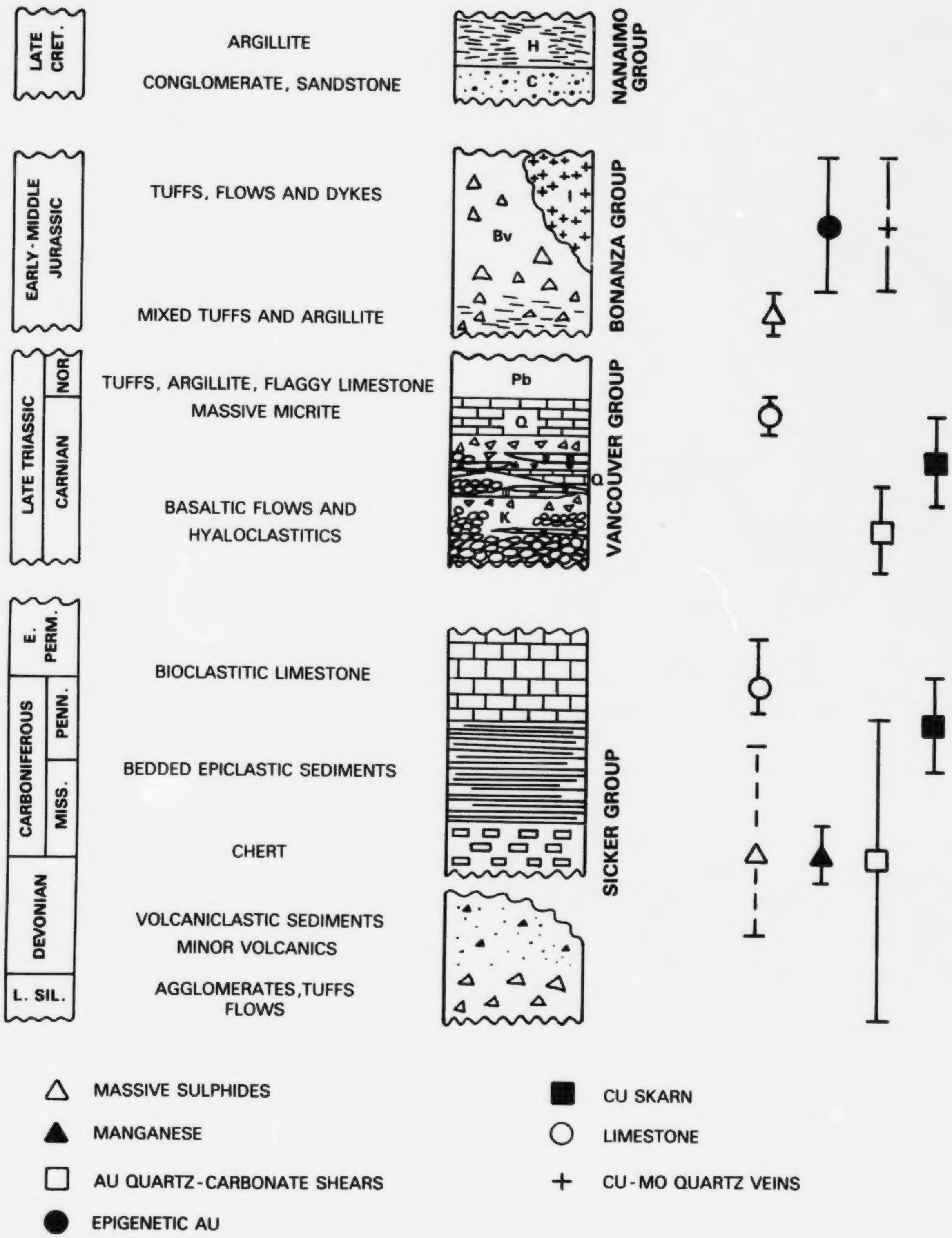

LATE CRET.
ARGILLITE
CONGLOMERATE, SANDSTONE
H
C
NANAIMO GROUP
EARLY-MIDDLE JURASSIC
TUFFS, FLOWS AND DYKES
MIXED TUFFS AND ARGILLITE
Bv
I
BONANZA GROUP
LATE TRIASSIC
NOR
CARNIAN
TUFFS, ARGILLITE, FLAGGY LIMESTONE
MASSIVE MICRITE
BASALTIC FLOWS AND
HYALOCLASTITICS
Pb
Q
Q
K
VANCOUVER GROUP
E. PERM.
CARBONIFEROUS
PENN.
MISS.
DEVONIAN
L. SIL.
BIOCLASTITIC LIMESTONE
BEDDED EPICLASTIC SEDIMENTS
CHERT
VOLCANICLASTIC SEDIMENTS
MINOR VOLCANICS
AGGLOMERATES,TUFFS
FLOWS
SICKER GROUP
△ MASSIVE SULPHIDES
▲ MANGANESE
□ AU QUARTZ-CARBONATE SHEARS
● EPIGENETIC AU
■ CU SKARN
○ LIMESTONE
+ CU-MO QUARTZ VEINS

Figure 3-9-3. Diagramatic stratigraphic section, not to scale, of the Cowichan Lake area (K = Karmutsen Formation; Q = Quatsino Formation; P = Parson Bay Formation; Bv = Bonanza Group; I = Island intrusions; C = Comox Formation; H = Haslam Formation). Stratigraphic distribution of mineral potential is illustrated on the right.

south shore of Cowichan Lake, northwest of Blue Grouse Mountain. Here they rest directly on Karmutsen Formation flows.

BONANZA GROUP

Unlike northern Vancouver Island, where the Bonanza Group can be subdivided into a lower sedimentary unit (Harbledown Formation) and an upper volcanic unit (Bonanza Volcanics) (Muller *et al.*, 1974), no subdivision is yet possible in the Cowichan Lake area. The Bonanza Group consists of a variety of maroon to green-grey, feldspar-phyric basalt and andesite flows, lapilli and crystal-tuffs, feldspar-hornblende andesite flows, dacite and felsic lapilli tuff, and various minor basalt, andesite and dacite dykes. There is a lack of lithologic continuity between outcrops and distinctive marker beds are absent.

Within the basal part of the sequence, sedimentary beds are found interbedded with lapilli and crystal-tuffs. They include maroon tuffaceous sandstone, orange-grey sandstone, granule sandstone and conglomerate, laminated sandy tuffs and argillites, and minor limestone and chert. Several beds have yielded macrofossil remains (gastropods, pelecypods and ammonites). Unfortunately none of the sediments appear to have any great lateral extent.

Rapid facies changes and poor stuctural control make estimates of thickness very uncertain. However, the Bonanza Group is estimated to be at least 1000 metres thick.

NANAIMO GROUP

Clastic sediments of the Nanaimo Group unconformably overlie older volcanic units and the Island intrusions. They outcrop mainly around the shores of Cowichan Lake, but are also preserved in fault-controlled valleys to the north of the lake, for example Meade Creek. The sediments constitute a major fining-upwards cycle, with conglomerates and sandstones of the Comox Formation succeeded by argillites of the Haslam Formation.

COMOX FORMATION

Basal sediments of the Comox Formation are usually coarse, poorly bedded cobble and boulder conglomerates which pass upwards into moderately to well-bedded sandstones, with interbedded pebble and granule conglomerates. Conglomerates have rounded clasts, although larger boulders are often angular. They are polymictic, including a variety of volcanic and intrusive lithologies generally of local origin. Sandstones are medium to coarse grained, grey with rusty weathered surfaces. They contain feldspar crystals and abundant lithic fragments, mostly volcanic of local provenance. Black plant fragments are characteristic of many beds. Occasionally calcareous concretions are developed with internal structure matching the enclosing sandstone and differing only in the calcareous cement. Many sandstones, and a few granule and pebble conglomerate beds, yield abundant fossil faunas, including gastropods, pelecypods, echinoderms, and nautiloids. The thickness of the Comox Formation is estimated to vary from 0 to 200 metres.

HASLAM FORMATION

The Haslam Formation consists of a characteristic rusty weathering, black argillite. It is fine to silty, poorly bedded, and friable, fracturing to pencil-shaped pieces. Calcareous nodules are common, averaging 10 to 15 centimetres but ranging up to 1 metre. Fossils are present but usually poorly preserved due to fracturing. Occasional interbeds of fine to medium-grained, grey silty sandstone are found within the argillites. They vary up to 1 metre thick and are massive to flaggy. The thickness of the Haslam Formation is estimated to vary from about 50 to 400 metres.

INTRUSIONS

ISLAND INTRUSIONS

Several granodioritic stocks occur in the area. They are coeval with the Bonanza Group volcanics, although they intrude all Paleozoic and Mesozoic formations. The stocks are irregular to elongate in shape with steep sides. The major lithology is a medium to coarse-grained, equigranular granodiorite to quartz diorite with a characteristic "salt-and-pepper" texture. Feldspars are white, though some pink staining is seen on weathered surfaces. Hornblende is the principal mafic mineral. It is usually tabular to acicular, black to green-black in colour and may be slightly larger in size than the feldspars. Biotite is only rarely observed. Chlorite replaces hornblende in altered rocks. Colour index varies from 10 to 20 in the granodiorites, but may range up to 40 in diorites. White, fine-grained aplite dykelets and veins crosscut the granodiorites.

Most of the stocks are rich in mafic inclusions, particularly in marginal zones were agmatitic intrusive breccias are developed. The angular to subrounded xenoliths are of local country rock lithologies. They show a range of amphibolitization and assimilation features. Complete assimilation results in gabbro-diorite with ragged mafic clots that may also contain inherited pyroxenes with white reaction rims.

Stocks north of Cowichan Lake have an elongate outcrop pattern, often with different stratigraphic units on either side, as with the Mount Buttle-Meade Creek stock. This suggests that the emplacement of granodiorite was controlled by pre-existing structures such as faults and possibly the axial regions of anticlinal folds. Stocks intruded into the Mesozoic sequences to the south of Cowichan Lake are more rounded in outcrop shape.

MINOR INTRUSIONS

Several lithologies are found as dykes and small irregular intrusions. Ages are not always known and can only be surmised until radiometric evidence is available. Many of these minor intrusions are probably of Jurassic age and related to Bonanza Group volcanics and Island intrusions. These include intermediate feldspar porphyry, feldspar-pyroxene porphyry, hornblende-feldspar andesite and minor diabase. Some of the porphyritic andesite dykes may be Tertiary in age.

Feldspar-quartz porphyry intrudes Sicker Group rocks and may be contemporaneous. It contains abundant white subhedral feldspars and sparse quartz in a dark green-grey to black aphanitic matrix. Coarse pyroxene-feldspar dykes, similar to Sicker Group porphyritc flows and agglomerates, intrude the area north of Cowichan Lake. Though some are probably of Sicker age, they are difficult to separate lithologically from the Jurassic pyroxene-feldspar porphyries.

Abundant diabase and feldspar diabase dykes of Late Triassic age intrude Sicker Group rocks and crosscut Karmutsen Formation volcanics. They vary in width from centimetres to 50 metres.

STRUCTURE

The area is divided into two regions of differing structural style by a major thrust fault running along the north side of Cowichan Lake. The northern region is underlain by Sicker Group rocks forming the southwest limb of the Horne Lake-Cowichan uplift. It is cut into several slices by a set of west-northwesterly trending faults paralleling the Cowichan Lake thrust, a high-angle contraction fault with a north-northeasterly dip of 65-80 degrees. Schistosity may be developed parallel to the fault in hangingwall rocks and extend over a zone of some 100 metres. Smaller shears to the northeast of the main fault have similar steep north-northeasterly dips and may represent minor imbrication planes in the hangingwall. Other major faults in the northern region are also suspected to be contractional, although, except for the Meade Creek fault, evidence is inconclusive. The thrusting involves Nanaimo Group strata dating it at Late Cretaceous to Tertiary. Pre-Jurassic faulting events are also suspected and may have exercised control on the emplacement of Island intrusions. Whether these earlier faults are extensional or contractional is unknown.

The Sicker Group rocks within the fault slices are deformed by a series of northwesterly trending folds. Where the plunges of the folds can be determined they are generally to the east-southeast. The folds are upright and overturning is very rare. They appear to predate the Island intrusions, though some tightening of the folds may have accompanied the thrusting event.

Pre-Nanaimo Group sequences south of Cowichan Lake form a syncline-anticline pair plunging to the northwest. Small crossfolds are also developed but are only defined where suitable bedded strata are seen. Northwest-trending faults parallel the major folds and may be related to the same deformational event. Nanaimo Group sediments are unconformable on the older sequences and appear to have been deposited in structurally controlled topographic lows. Compression accompanying the Late Cretaceous-Tertiary thrusting event reactivated some of these faults and folded the Nanaimo Group.

METAMORPHISM

Metamorphic grade in the area is generally quite low, but increases with the age of the rocks. Bonanza Group rocks are veined and show minor replacement by laumontite, stilbite, calcite and minor quartz, assemblages typical of the zeolite facies. Basalts of the Karmutsen Formation show amygdule infillings and veins of chlorite, calcite, epidote and quartz. Similar assemblages are found in Sicker Group rocks. Contact metamorphism of the hornblende hornfels facies is locally developed around Island intrusion stocks, particularly in the McKay Creek area.

MINERAL DEPOSITS

No mines are presently active in the Cowichan Lake area, although several small deposits have been worked in the past. However, exploration is very active, particularly in areas underlain by the Sicker Group. Several types of mineral deposit (Figures 3-9-3 and 3-9-4) are present:-

(1) **Volcanogenic, gold-bearing massive sulphides** — These are the principal target in the Sicker Group rocks following the success of exploration at the Buttle Lake mine. The relatively poor development of felsic volcanics in the Sicker Group of the Cowichan Lake area may mitigate against repeating such finds, although sulphide-rich argillite is found interbedded with cherts. Potential for auriferous massive sulphides may also exist within the Bonanza Group volcanics; sulphidic argillites are found interbedded with tuffs in the basal part of the sequence in the Nixon Creek area.

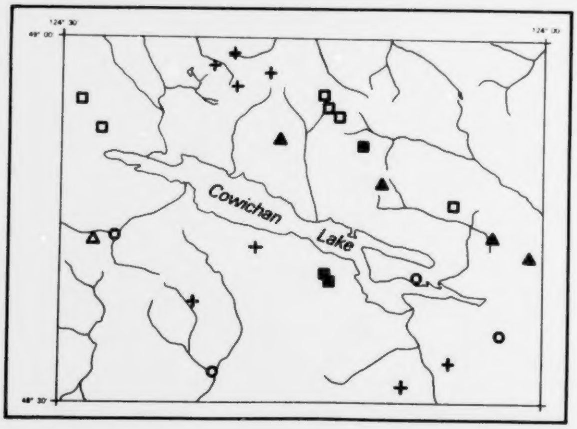


Figure 3-9-4. Distribution of mineral occurrences in the Cowichan Lake area. Symbols for mineral types as in Figure 3-9-3.

(2) **Manganese deposits** — Manganese minerals are found in lenticular masses in several places in the cherts of the Sicker Group. Rhodonite is the primary manganese mineral; manganese garnets, rhodochrosite and manganite have also been reported. Oxidized deposits near Hill 60 were worked for manganese ore in 1919-20, but the main potential for these deposits is for lapidary uses. Reported localities (with MINFILE designation) are Rocky-Widow Creek (113), Wardroper (114), Meade (115) and Stanley Creek-Lookout locality (116).

(3) **Gold-bearing, pyrite-chalcopyrite-quartz-carbonate veins along shears** — Many of the faults and shears cutting the Sicker Group and Karmutsen Formation sills north of Cowichan Lake are veined by rusty weathering quartz-carbonate. The veins vary in thickness up to about 1 metre, and are very variable in lateral extent. The carbonate is principally ankerite and calcite. Sulphides are common with pyrite, pyrrhotite, chalcopyrite and arsenopyrite reported. Occurrences investigated in the past include El Capitan (19), Cottonwood (20), Silver Leaf (21), Paint Pot (43) and Candy (76).

(4) **Epithermal gold-silver deposits** — Bonanza Group volcanics are intruded by abundant shallow and medium-level intrusives. This may have been favorable for the formation of epigenetic precious metal deposits. Faulting and fracturing of the rocks are ubiquitous, though usually accompanied by zeolite alteration only. At present the prospecting level within the Bonanza Group is low and an adequate assessment cannot be made.

(5) **Copper skarns** — Zones of chalcopyrite-bearing skarn have been worked at two localities. The Blue Grouse (17) and neighbouring Sunnyside (108) properties are underlain by Karmutsen Formation basalts and Parson Bay sediments, cut by numerous Jurassic feldspar and feldspar-pyroxene porphyry dykes. Skarns are developed in limy sediments apparently interbedded with the basalts. Garnet, epidote and actinolite occur as gangue in the skarn. On the Comego property (18), skarns are developed in Sicker Group sediments intruded by Karmutsen Formation diabase sills. However, mineralization may be related to the nearby Jurassic Reynard Creek stock. Chalcopyrite is accompanied by pyrite, pyrrhotite, magnetite and minor molybdenite. Quartz, calcite and garnet are the main gangue minerals. Other skarn occurrences are known in the area, especially in the area south of Cowichan Lake, but in general skarns have little economic potential today.

(6) **Limestone** — Limestones of the Sicker Group (Buttle Lake limestone) and the Quatsino Formation have been exploited for cement manufacture elsewhere on Vancouver Island. Although both limestones have been prospected within the map area [Buttle Lake limestone on Fairservice Creek (15) and Marble Bay (16) properties; Quatsino Formation in Gordon River (86) and Nixon Creek (87) areas], none have been worked.

(7) **Copper-molybdenum quartz veins** — Sulphide-bearing quartz veins occur in granodiorite and adjacent country rock on several properties. Chalcopyrite and pyrite, with or without molybdenite, are the principal sulphides; minor sphalerite, galena and arsenopyrite are also reported. Veins

are usually less than 1 metre wide. Reported prospects are Delphi (13), Mount Buttle-Allies (14), Lorry (35), Viking (42), Paget (46), AB (75) and Close (112).

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GEOLOGY AND MINERAL POTENTIAL OF THE CHILKO LAKE AREA*

(92N/1,8; 92O/4)

By G. P. McLaren

INTRODUCTION

During the 1985 field season the author initiated a mineral potential evaluation of the mountainous terrain in the Chilko-Taseko Lakes area, 230 kilometres north of Vancouver (McLaren, 1986a). In 1986 this study was extended to the west of Chilko Lake to continue 1:50 000-scale mapping and prospecting, together with lithogeochemical and stream sediment sampling. In addition, mapping was completed in the area between the Tchaikazan and Falls Rivers that was stream sediment sampled in 1985. Follow-up of anomalous geochemical results from the 1985 survey in this area resulted in the location of a new arsenic-bearing mineral showing.

Approximately 600 square kilometres were covered by the 1986 stream sediment sampling survey west of Chilko Lake. Mapping and lithogeochemistry within this area varied in detail depending on accessibility, complexity of geology and indications of mineralization. As in the previous year, all geological and geochemical data are being compiled for release as open file publications.

REGIONAL GEOLOGY AND PREVIOUS WORK

The geology of the area was first mapped in 1924 by Dolmage (1925), who broadly divided the stratified rocks into Triassic and Cretaceous formations. The Mesozoic volcanic and sedimentary stratigraphy of the Mount Waddington (92N) and Taseko Lakes (92O) map sheets has been mapped by Tipper (1969, 1978). Upper Jurassic and Lower Cretaceous rocks of this area accumulated in the northwest-trending Tyaughton trough, a sedimentary basin bounded by intermittent land masses on the northeast and southwest. The area has been cut by numerous right-lateral transcurrent faults and the stratified rocks now lie along the northeastern flank of the Coast Plutonic Complex.

Jeletzky and Tipper (1968) described a faunal stratigraphy for the Taseko Lakes map sheet and discussed the role of the Tyaughton trough in the geological history of southwestern British Columbia. The rocks in the current study area record a volcanic island arc environment on the southwest flank of the Tyaughton trough, as opposed to the dominantly clastic sedimentary environments in the axial regions of the trough (McLaren, 1986a).

Work completed between Chilko and Taseko Lakes in the 1985 season identified a section of Lower and Upper Cretaceous sediments and volcanics similar to that previously mapped by Tipper (1978). A number of fossil collections obtained in this work have since been identified and dated by J.A. Jeletzky of the Geological Survey of Canada. Correlations and ages previously proposed (McLaren, 1986a, Table 41-1) appear valid; the following comments on fossil ages apply to rock units described in the 1985 work. Correlations between unit numbers given to rocks mapped in 1985 and 1986 are discussed elsewhere in this paper and are shown in Table 3-10-1.

An *Inoceramus* fauna collected from Unit 1 was dated as a general Hauterivian age and was suggested to be younger than, or contemporaneous with, two collections made from Unit 4. Of the three collections taken from Unit 4, two indicated an early Hauterivian age while the third indicated a Hauterivian to Barremian age and is likely of the same early Hauterivian age as the others. Unit 4 was previously correlated with fossiliferous rocks of the Relay Mountain Group (Jeletzky and Tipper, 1968; McLaren, 1986a). Unit 5 yielded an ammonite and pelecypod collection representing a late Early Albian age and a gastropod collection with a general Albian age; these rocks have been correlated with the Taylor Creek Group.

All of the above ages conform with the previously proposed stratigraphy and correlations and suggest that Units 1 through 4 represent a partially contemporaneous succession of volcanic rocks and sediments that accumulated as overlapping lateral facies equivalents. This supports the suggestion that both Units 2 and 4 conformably underlie the mixed volcanics and sediments of Unit 5 (McLaren, 1986a).

A collection of pelecypods was taken from limy and argillaceous sediments, immediately north of the Tchaikazan fault, that were mapped as Unit 6 and correlated with Kingsvale Group sediments of Albian to Cenomanian age. These pelecypods have been tentatively dated as a general Hauterivian to Aptian age. This age suggests either that fault wedges of Lower Cretaceous sediments occur with similar younger lithologies along the Tchaikazan fault zone, or that the sedimentary sequence north of the fault represents a conformable Lower to Upper Cretaceous section. A conformable sedimentary facies of this age is more likely to represent rocks deposited closer to the axis of the Tyaughton trough and which must therefore have been transported along transcurrent faults to their present position adjacent to the Hauterivian to Albian island arc environment. These sediments pass into an overlying succession of volcanic rocks regionally correlated with the Kingsvale Group of Late Cretaceous age (Tipper, 1978).

LOCAL GEOLOGY

Figure 3-10-1 outlines the general geology of the area west of Chilko Lake mapped in 1986 and Figure 3-10-2 displays geological cross sections of the area. Previous regional mapping by Tipper (1969) again provided an invaluable guide to following contacts of rock units. A number of stratigraphic interpretations, different from those of Tipper, are presented here and are based on lithologic relationships observed in the 1986 fieldwork. A limited amount of data from assessment reports in the Franklyn Arm area has been incorporated into the mapping. Stratigraphic and structural relationships in the extreme northwestern corner of the map area are somewhat speculative as only a few reconnaissance traverses were completed. The interpretations may be subject to revision pending dating of fossil collections obtained in this work.

STRATIFIED ROCKS

UNIT 1

The oldest rocks exposed in the map area consist of an interbedded sequence of intermediate to basic volcanic flows and pyroclastic rocks, fine clastic sediments and limestones, that outcrops in fault-bounded wedges within Deschamps Creek valley and

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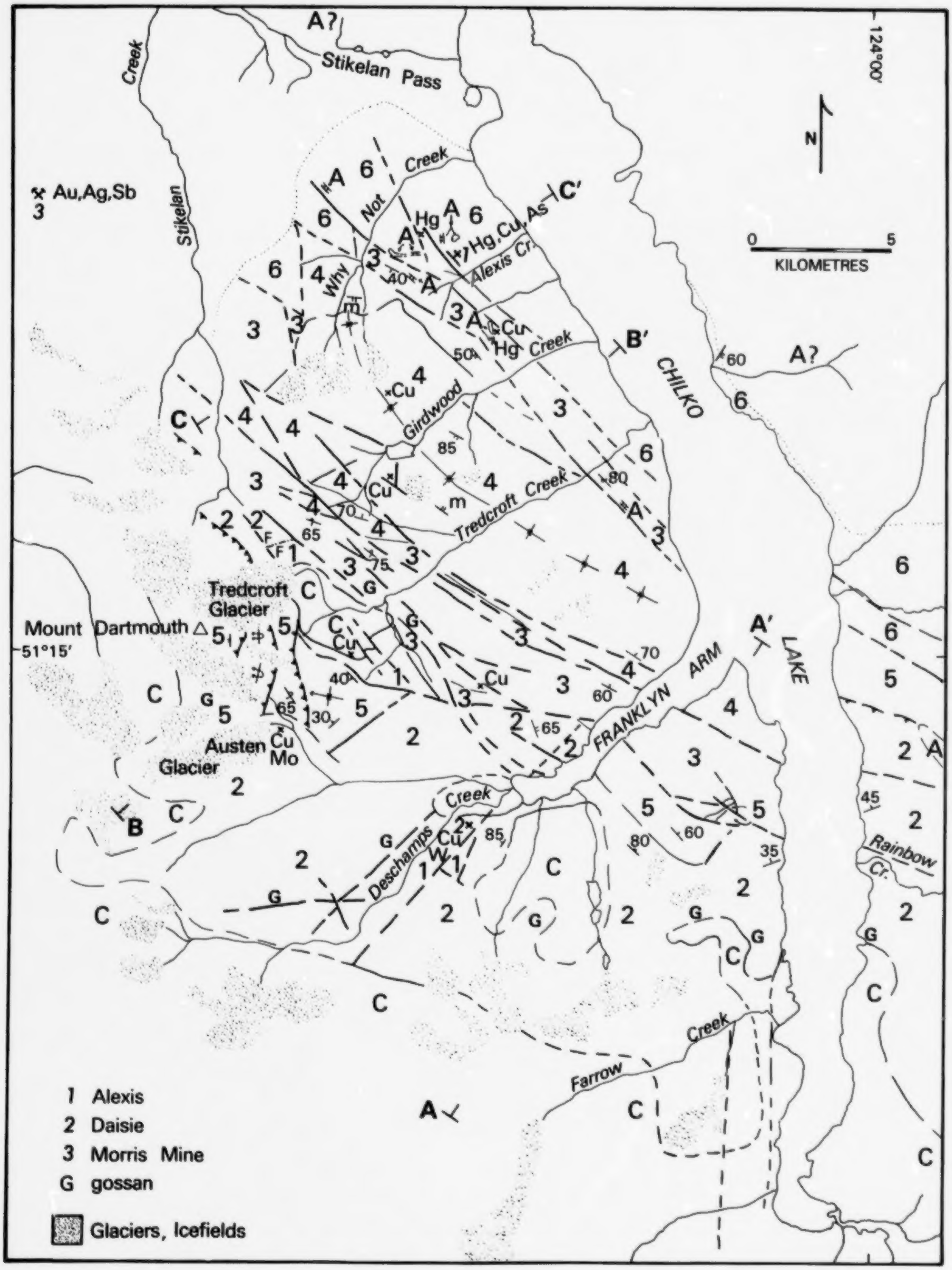
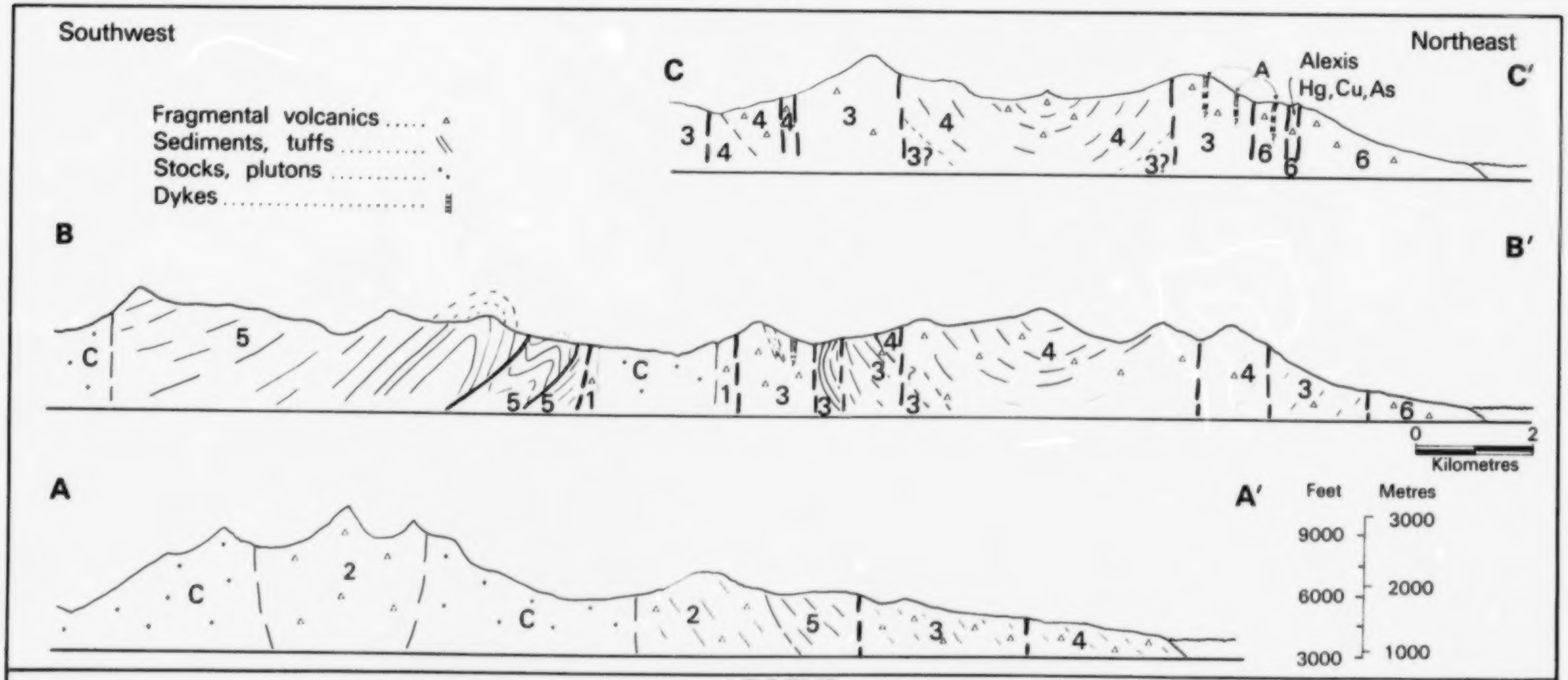
* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.



124°00'
N
0 5
KILOMETRES
Stikelan Pass
Stikelan Creek
Not Creek
Why
Alexis Cr.
Girdwood Creek
Tredcroft Creek
Tredcroft Glacier
Mount Dartmouth
51°15'
Austen Glacier
Deschamps Creek
Farrow Creek
Rainbow Cr.
CHILKO LAKE
FRANKLYN ARM
A?
A
A'
B
B'
C
C'
Au,Ag,Sb
Hg
Hg,Cu,As
Cu
Cu Mo
Cu W
m
F
G
1 Alexis
2 Daisie
3 Morris Mine
G gossan
Glaciers, Icefields

Figure 3-10-1. Geology west of Chilko Lake.


Southwest
Northeast
Fragmental volcanics ..... ▵
Sediments, tuffs .... \\
Stocks, plutons .... ·.
Dykes ....
C
C′
B
B′
A
A′
Alexis
Hg,Cu,As
A
3
4
6
3?
5
1
C
2
0
2
Kilometres
Feet
Metres
9000
6000
3000
3000
2000
1000

LEGEND

STRATIFIED ROCKS

CRETACEOUS

CENOMANIAN

6	*Andesitic to basaltic pyroclastics, flows and volcanic sediments; minor greywacke and argillite*

ALBIAN

5	*Quartzose sandstone, chert pebble conglomerate, argillite, minor siltstone*

HAUTERIVIAN

4	*Purple andesitic pyroclastics, minor flows; purple greywacke and conglomerate*
3	*Rhyolitic to basaltic pyroclastics and flows, volcanic sediments; quartzose sandstone, greywacke, argillite*

STRATIFIED ROCKS *(Continued)*

2	*Rhyolitic to basaltic pyroclastics and flows, volcanic sediments, minor siltstone and greywacke*

TRIASSIC

1	*Andesitic to basaltic flows and tuffs; argillite, siltstone, limestone*

INTRUSIVE ROCKS

A	*Diorite stocks, dykes: hornblende diorite*
C	*Coast Plutonic Complex: granodiorite, quartz diorite*

Figure 3-10-2. Geological cross-sections to accompany Figure 3-10-1.

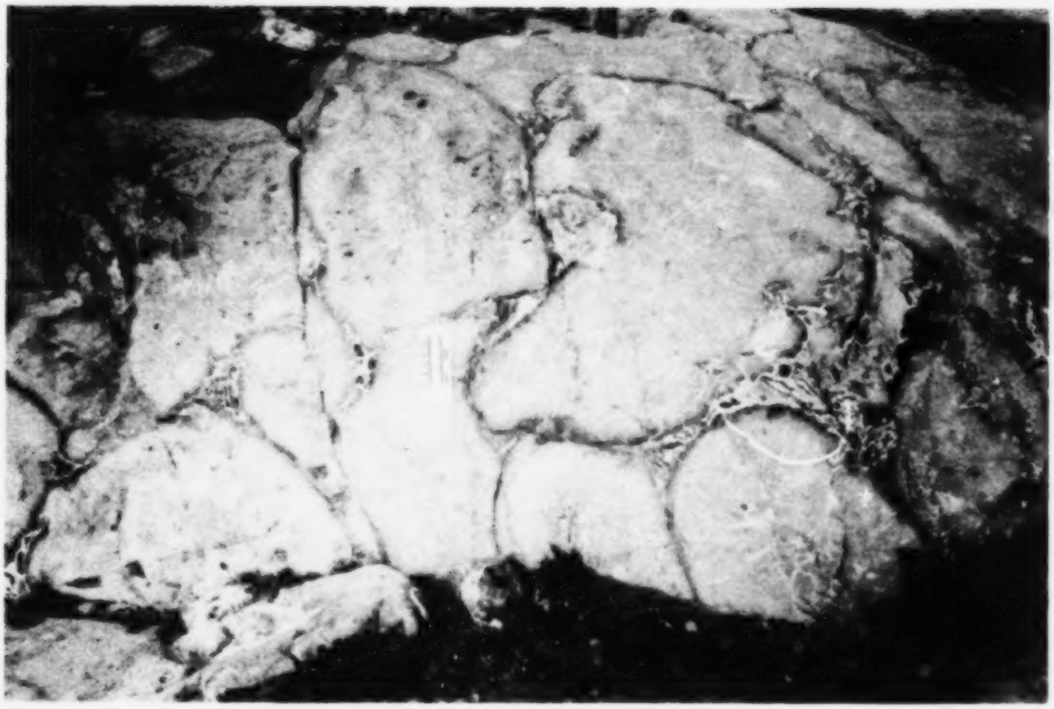


Plate 3-10-1. Pillow basalts of Unit 1.

Plate 3-10-2. Chaotic debris flows of Unit 2, east shore of Chilko Lake.

TABLE 3-10-1. CRETACEOUS STRATIGRAPHIC CORRELATIONS

Age		Lithologies	This Paper 92N	McLaren 1986 92O	Tipper 1978 92O	Tipper 1969 92N
Late Cretaceous	Cenomanian	volcanics	6	7		19
		sediments		6	Kingsvale Group	18
	Albian Aptian	volcanics and sediments	5	5a 5b	Taylor Creek Group	16
Early Cretaceous		sediments		4	Relay Mountain Group	9
	Hauterivian	volcanics	4 3 2	3 2	lkv	15 ↕
		sediments		1		12
Late Triassic		volcanics and sediments	1			1

at the headwaters of Tredcroft Creek. Intrusive stocks cut these rocks in both locations and have developed extensive hornfels zones in the Deschamps Creek area.

Volcanic lithologies predominate and consist of intermediate to basic flows, interflow breccia and associated lithic fragmental tuffs. Pillowed basalt flows are well exposed on the ridge dividing the southern headwaters of Tredcroft Creek (Plate 3-10-1). The pillows are up to 1 metre across and are composed of aphanitic dark grey material with numerous siliceous, calcareous or chloritic amygdules. Radial cooling fractures filled with quartz are common. Interpillow material consists of chloritized pillow fragments set in a siliceous or pale grey clay-rich matrix. Massive nonpillowed flows are present, as are horizons of interflow breccia. Feldspar-augite crystal to lithic fragmental tuffs and breccias, reworked volcanic epiclastic rocks and some argillaceous sediments displaying flame structures, scours and volcanic bombs, are interbedded with the flow units.

Elsewhere purple or green, coarse lithic fragmentals predominate. These rocks have been thoroughly fractured and infilled by an anastamosing network of quartz-carbonate veins. North of Tredcroft Glacier grey crystalline limestone containing pelecypod shell fragments is interbedded with limy argillaceous sediments and fine lithic to crystal tuffs.

In Deschamps Valley similar volcanics and sediments have been cut by a diorite to quartz diorite stock of the Coast Plutonic Complex. Here the limestones have been recrystallized to a grey, massive, sugary marble with local development of copper-bearing garnet diopside skarn zones. The marbles occur within a broader section of hornfelsed clastic sediments and tuffaceous volcanic rocks.

These rocks have previously been dated as Late Triassic by Tipper (1969) on the basis of fossils located north of Tredcroft Glacier. The contact with overlying sediments at this locality appears to be unconformable with only a small angular discordance, as reported by Tipper. In all other areas these Triassic rocks are in fault contact with adjacent units. The limy and hornfelsed rocks in Deschamps Valley are attributed to this Triassic section on the basis of lithologic similarities. The occurrence of intrusives and faults in both locations indicates that these rocks have been structurally uplifted and exposed through erosion.

UNIT 2

A thick succession of volcanic rocks with lesser gritty sediments is in contact with intrusives of the Coast Plutonic Complex in the southern portion of the study area. The volcanics comprise a varicoloured and well-differentiated suite ranging from rhyolite to basalt in composition. Crystal and fragmental tuffs dominate but rhyolite and columnar basalt flows are also present.

The finer tuffs generally display feldspar or mafic crystals and crystal fragments distributed through an ash-like grey, maroon or green matrix. They grade through lapilli tuffs into coarser lithic fragmentals with subrounded to angular clasts of locally derived volcanics. Carbonates are often present in the matrix or as discrete pods. Tuffs may be subaerial or waterlain and are regularly interbedded with reworked epiclastic material. These rocks are dominantly andesitic to dacitic in composition.

Basic flows are interlayered with the tuffs, generally forming more massive, resistant horizons. A prominent bluff on the west shore of Chilko Lake exposes well-developed columnar jointing in a fine-grained grey basalt. This flow overlies a layered volcanic breccia to laharic mudflow section. The lahars contain coarse volcanic boulders irregularly dispersed through a white-weathering ash-like matrix. Similar lithologies form distinctive white cliffs along strike on the east shore of Chilko Lake. Here, in excess of 1 kilometre of shoreline provides excellent exposure of a chaotic volcanic conglomerate with a layered ash flow or muddy matrix (Plate 3-10-2). Fine-grained portions of this section are thinly laminated and display some crossbedding features. Similar lithologies were mapped within this unit near Mount Goddard during the 1985 season (McLaren, 1986a, page 265).

Rhyolitic volcanics occur throughout this unit. Layered quartz-eye tuffs pass into massive quartz-feldspar porphyry north of Franklyn Arm. To the south, along strike, similar tuffs are interbedded with lithic fragmentals of a more typical intermediate composition. Rhyolitic fragmentals carrying considerable pyrite and pyrrhotite occur along the contact of the Coast Plutonic Complex on the east side of Chilko Lake.

Sedimentary strata of Unit 2 consist primarily of siltstones and greywackes that are associated with volcanically derived epiclastic material. Prismatic shell fragments, likely from the pelecypod ***Inoceramus***, were found in a layered hornfelsed limy siltstone on the western slopes of Deschamps Valley. Similar volcanics and sediments containing ***Inoceramus*** shells and other pelecypods were noted north of Tredcroft Glacier; these fossiliferous sediments were previously dated as Hauterivian by Jeletzky (1968).

These rocks unconformably overlie Triassic rocks as described for Unit 1; elsewhere the base of this unit is not exposed as it is in contact with rocks of the Coast Plutonic Complex in the south. The upper contacts are generally not exposed except on the ridge between Franklyn Arm and Chilko Lake where these volcanics are conformably overlain by clastic sedimentary rocks of Unit 5. On the ridge crest the volcanic rocks grade into the sediments with no major breaks, while in a creek valley to the east the sediments and volcanics clearly interfinger. The creek valley lies along a fault zone containing numerous slivers of mixed volcanic and sedimentary lithologies, however the faults do not separate lithologies. Unit 2 is in fault contact with the mixed volcanics and sediments of Unit 3, however similar lithologies on either side of the fault mask the true nature of the stratigraphic relationship between these units.

UNIT 3

Interbedded sediments and volcanics of Unit 3 can be subdivided into a lower dominantly volcanic section and an upper dominantly sedimentary section. These rocks are lithologically similar to rocks of Unit 2 and may be a lateral facies equivalent.

The lower volcanic assemblage comprises green, purple or brown pyroclastics and flows of intermediate to felsic composition. They are characterized by feldspar-hornblende crystal tuffs that grade into coarser lapilli and lithic fragmental tuffs with locally derived volcanic clasts. Laharic deposits with a fine white ash-like matrix resemble those described in Unit 2. Flow-banded rhyolite and quartz-eye tuffs are present in two localities north of Franklyn Arm, and again resemble Unit 2 rocks in this area. This is the lowest unit in which cherty pebbles are noted in volcanic conglomerates and may be indicative of developing tectonic uplift in adjacent areas and deposition of externally derived clastic material; such material becomes common in the overlying sediments.

Minor argillaceous beds are present within these volcanics. A pyrite-pyrrhotite-rich gossanous zone has developed on one such horizon, on ridges north and south of Tredcroft Creek.

North of Tredcroft Creek clastic sediments increase in the section and become predominant. They consist of interbedded quartz-rich sandstones, immature greywacke, dark grey to green silty to argillaceous beds, and minor conglomerates. Thin limy horizons are also present. Argillaceous beds are either extremely friable and sheared or tightly contorted. Gritty sediments display bedding features facing northeast. Numerous volcanic tuffs and possibly some flows are interbedded with the sediments.

The contact with overlying purple sediments and volcanic rocks is gradational and reflects a change from neritic to subaerial conditions. Mixed sediments and volcanics in the headwaters of Alexis Creek, and south and west of the head of Why Not Creek, were mapped with this unit based on lithological similarities, a conformable contact with the overlying purple rocks and on their position around the broad synclinal structure cored by the purple volcanics of Unit 4.

Strong faulting and shearing are evident in the sedimentary sections of this unit in both the eastern and western portions of the map area. North of Tredcroft Creek the sediments are overturned and are shattered at one location and tightly contorted at another. These rocks are particularly susceptible to deformation and appear to have deformed in a more ductile fashion than the surrounding volcanics.

UNIT 4

A thick succession of distinctive purple volcanics and sediments forms the core of a broad syncline in the centre of the area mapped. The base of the unit is dominantly sedimentary, but it passes quickly into a volcanic sequence dominated by pyroclastic rocks. These rocks are lithologically similar to, and conformably overlie, sediments and volcanics of Unit 3, however due to their distinctive colour and probable subaerial deposition they are mapped separately.

The sediments of Unit 4 comprise a well-bedded sequence of greywackes and conglomerates that often grade into epiclastic volcanic material. The base is clearly transitional with the white quartzose sediments and argillites of Unit 3, but tuffaceous and argillaceous clasts, set in a matrix containing detrital hematite, become more common as these rocks pass upwards into the overlying volcanics. Single beds may change colour along strike, probably reflecting variations in hematite content. The only fossils located in these sediments were gastropods; no clearly marine fossils were found.

Pyroclastic rocks dominate the volcanic lithologies; feldspar or feldspar-hornblende crystal tuffs grade into lithic fragmental tuffs and breccias. Fragments are angular to subrounded, purple or green and are locally derived. The matrix is often calcareous and may be magnetic; chlorite and epidote alteration is common. More massive flows or irregular subvolcanic intrusive bodies of augite-feldspar porphyry occur within the pyroclastics. Layered epiclastic horizons are occasionally present, but bedding is not well developed in the tuffs.

This unit forms prominent rugged peaks in the centre of the map area. Quartz-carbonate veins with epidote selvages are common where the rocks are fractured. The strongest development of veining occurs north and south of Girdwood Lake where epidote alteration is noted in zones up to 2 metres wide and minor copper mineralization is present in the veins (*see* section on mineralization).

No contact was observed between Unit 4 rocks and younger units. The basal contact is shown as a fault in many locations, but this is uncertain due to the similarities of lithologies in Units 3 and 4.

UNIT 5

Well-bedded quartz and chert-rich clastic sedimentary lithologies occur in a series of stacked thrust sheets near Tredcroft Glacier and as a distinct layered section between Franklyn Arm and Chilko Lake. Argillaceous rocks are interbedded with the coarser clastics and tuffaceous horizons are also present. Fossilized logs, leaf and stem impressions, and pockets of organic debris are characteristic of this unit.

Conglomeratic horizons, most common lower in the section, are usually discontinuous channel or floodplain deposits. Chert and quartz generally account for 80 to 85 per cent of the clasts; argillite and some volcanics make up the remainder. Clasts are set in a gritty quartzose matrix. Sandstones are grey to white, clast-supported quartz-rich rocks with sparse, weakly calcareous cement; argillite grains are locally present. Dark grey argillites and some siltstone are interbedded with the coarser rocks. Occasionally these become

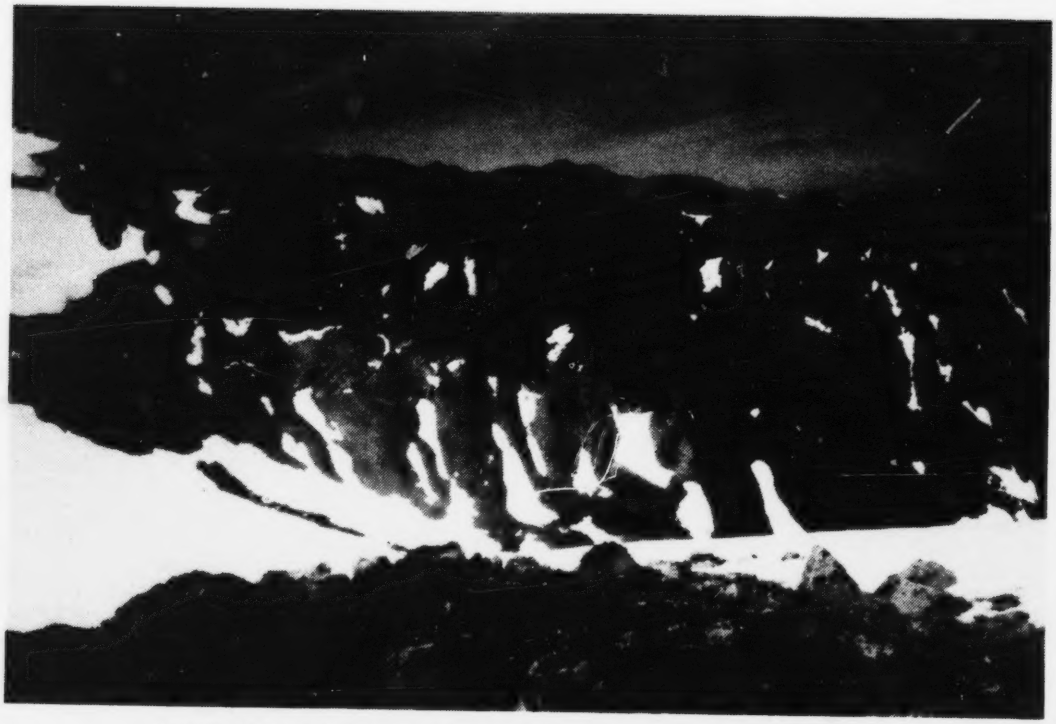


Plate 3-10-3. Imbricate thrust sheets in Unit 5 sediments, east of Mount Dartmouth.

Plate 3-10-4. Recumbent dragfolds associated with thrusting, at the toe of Hamilton Glacier (Mount Dartmouth in background).

greenish and appear glauconitic. Brown calcareous concretions weather out of the finer sediments as large round balls. Tuffaceous or volcanic epiclastic material, represented by feldspar crystals or broken crystal pieces, was noted in a number of horizons.

A variety of bedding features, including crossbedding, graded bedding, channel scours and flame structures, indicate a northeasterly facing sequence with a westerly source. Individual beds often lens out laterally or are cut off by channels. All the above features strongly suggest a relatively active deltaic environment. Furthermore pockets of carbonized organic debris are common. Fossilized logs can be found in several localities including high above the west shore of Chilko Lake (Fry, 1959) and in the headwaters of Tredcroft Creek. A number of samples were taken from these rocks for possible microfossil identification. Similar quartz and chert-rich clastic rocks carrying fossilized log fragments were mapped in the Tchaikazan Valley in 1985 and were thought to conformably overlie a volcanic succession equivalent to Unit 2 rocks.

The base of this unit was only observed on the ridge west of Chilko Lake, where these sediments are interbedded with volcanics of Unit 2. Elsewhere all contacts appear fault-related or are covered. Numerous thrust faults cut the unit at the head of Tredcroft and Torch Creeks where spectacular recumbent dragfolds are exposed (Plates 3-10-3 and 3-10-4).

UNIT 6

Intermediate to basic volcanic pyroclastics, flows and conglomerates of Unit 6 outcrop on the slopes along both shores of Chilko Lake. Purple and green feldspar crystal tuffs, lapilli tuffs and lithic fragmentals predominate. Angular lithic fragments are up to 15 centimetres across and are generally composed of locally derived feldspar crystal tuffs. These occasionally grade into horizons of volcanic conglomerate with well-rounded volcanic boulders up to 20 centimetres across resting in a tuffaceous or epiclastic matrix. Pyroclastics are often calcareous and may be magnetic. Finer grained, more massive grey flows, with fine mafic needles, are locally intercalated in the tuffs. All of these lithologies are distinctly similar to rocks correlated with Kingsvale volcanics and mapped along strike just east of Chilko Lake in 1985 (McLaren, 1986 a and b, Unit 7).

Minor clastic sedimentary rocks are present within Unit 6 volcanics in the vicinity of Alexis Creek. They are generally greywackes and argillites. On the east shore of Chilko Lake, a limited collection of gastropods and pelecypods was taken from similar sediments that were previously mapped as Kingsvale Group by Tipper (1969).

Unit 6 rocks appear to be fault-bounded in all parts of the map area, however, the similar lithologies across the faults and the reconnaissance nature of mapping in the northwest makes this uncertain.

INTRUSIVE ROCKS

UNIT A — DIORITE STOCKS, DYKES

A number of irregularly shaped diorite to quartz diorite intrusions occur within a broad zone of faulting on the slopes to the west of Chilko Lake. These rocks display medium to fine feldspar and hornblende phenocrysts crowded in a fine crystalline matrix. Partially chloritized biotite is a common constituent; quartz and magnetite are generally minor accessories. They are well fractured, discontinuous and clay or carbonate alteration is common. Diorite stocks mapped east of Chilko Lake during 1985 also appear spatially related to fault zones.

UNIT C — COAST PLUTONIC COMPLEX

Massive granodiorite and quartz diorite intrusions of the Coast Plutonic Complex outcrop in the southern and southwestern portions of the area. No attempt was made to map these in detail. Satellite stocks of similar rocks were seen at the head of Franklyn Arm and Tredcroft Creek. Extensive hornfelsing, accompanied by disseminated or veinlet pyrite-pyrrhotite mineralization, is common throughout the volcanic and sedimentary rocks of Unit 2 adjacent to the stocks. The irregular shape of the intrusive contacts, and the extensive hornfelsing between Franklyn Arm and Chilko Lake, suggest that intrusive rocks underlie much of the area at a relatively shallow depth. These intrusions are presumably responsible for the skarn development in Deschamps Valley.

STRATIGRAPHIC CORRELATIONS

Work completed east of Chilko Lake in 1985 outlined a Hauterivian to Cenomanian succession of volcanics and sediments correlative in part with the Relay Mountain Group, Taylor Creek Group and Kingsvale Group (McLaren, 1986a, Table 41-1). It was further suggested that these Lower Cretaceous units could be correlated with the Gambier Group of the southern Coast Mountains.

The mapping completed in 1986 extended the previously documented stratigraphy and similar correlations can be drawn. However, as the sections mapped in 1985 and 1986 differ in character, the rock unit numbers used each year are not directly correlative. Table 3-10-1 shows the rock unit correlations from the two seasons of this project and compares them with those of Tipper (1969, 1978).

Triassic rocks mapped this year were not seen east of Chilko Lake in 1985. Volcanics and sediments of Unit 2 (1986) are equivalent to those of Unit 2 (1985), and the purple volcanic unit mapped as Unit 4 (1986) is equivalent to Unit 3 (1985). The intervening sediments and volcanics mapped as Unit 3 (1986) appear to be a facies change from the purple volcanics and are likely correlative with parts of the Units 2 and 3 mapped in 1985. All of these rocks, on both sides of Chilko Lake, record a Hauterivian volcanic island arc environment with both marine and subaerial deposition and localized sedimentary basins. These rocks are correlative as a package, but the relative locations of sediments and volcanics in a stratigraphic column may vary.

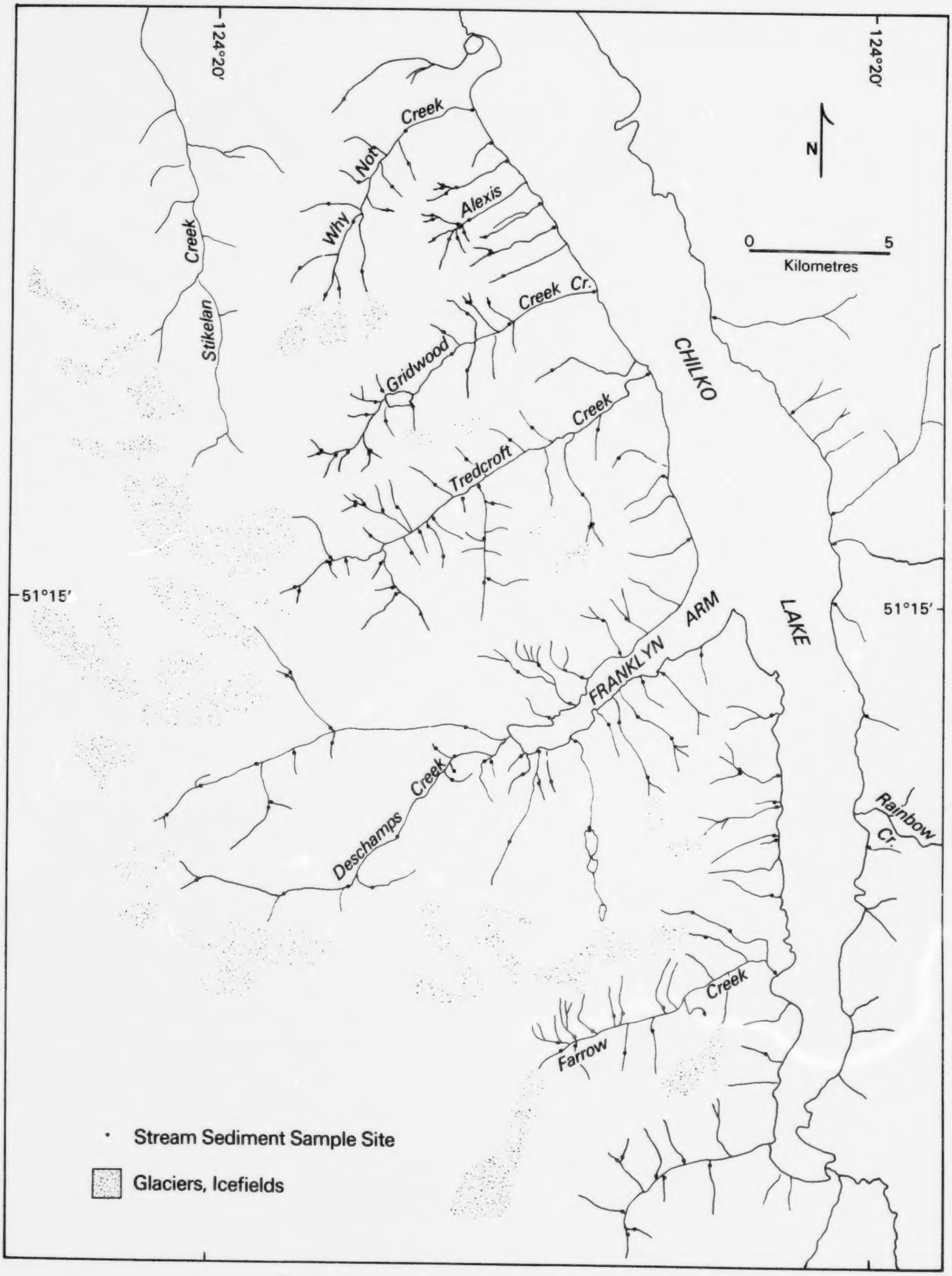
The fossiliferous rocks attributed to Unit 4 (1985) were not located in 1986. They are probably contemporaneous with the Hauterivian island arc and may record a final stage of the previously more widespread sedimentary deposition of the Relay Mountain Group.

An incursion of westerly derived clastic sediments carrying organic debris is recorded by Unit 5 (1986). Similar rocks are located within Unit 5b (1985) on the east side of Chilko Lake; these sediments interfinger with the broader volcanic and sedimentary assemblage of Unit 5, given an Albian age and correlated with the Taylor Creek Group in 1985.

Volcanic rocks mapped in Unit 6 (1986) are correlative with those of Unit 7 (1985). They are temporally equivalent with the Kingsvale Group.

STRUCTURE

Northwesterly trending transcurrent faults dominate the structural geology of the area. Tipper (1969) has previously indicated that two major structures, the Tchaikazan and Stikelan faults, cut through the map area. Two broad zones of multiple faulting with complex deformation are present in the current study area. A zone along the west side of Chilko Lake, and probably extending beneath it, marks the trace of the Tchaikazan fault. Tipper has suggested that


124°20'
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Alexis
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Stikelan
Gridwood
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Cr.
CHILKO
LAKE
Tredcroft
Creek
51°15'
51°15'
FRANKLYN
ARM
Deschamps
Creek
Rainbow
Cr.
Farrow
Creek
• Stream Sediment Sample Site
▨ Glaciers, Icefields

Figure 3-10-3. Stream sediment sample site locations.

this fault may have in excess of 30 kilometres of right lateral displacement. Intense shearing of carbonaceous argillites, slickensiding, and juxtaposition of volcanics and sediments were noted in canyons in lower Tredcroft Creek. Prominent zones of pervasive, orange-weathering carbonate alteration containing strongly silicified fractures are seen further north at Alexis Creek. Multidirectional slickensides are characteristic of this zone. Numerous dioritic intrusions have invaded the zone and epithermal copper-mercury mineralization occurs within the alteration zones at Alexis Creek. Extensions of these faults were mapped to the southwest in 1985 and were found to be associated with dioritic intrusions and to contain copper mineralization and anomalous mercury concentrations at various locations.

A second zone of faulting trends across Franklyn Arm to the headwaters of Stikelan Creek. Here argillaceous rocks have been intensely sheared and locally contorted into tight irregular minor folds. A large section of rocks north of Tredcroft Creek has been steeply overturned along the fault zone, possibly in conjunction with thrusting from the southwest. The Stikelan fault lies within this zone

Multiple northeasterly facing thrust faulting is clearly evident in the well-bedded sediments of Unit 5 to the south of Tredcroft Glacier. Stacked thrust sheets with spectacular recumbent dragfolds (Plates 3-10-3 and 3-10-4) attest to considerable stratigraphic shortening in this area. West of these thrusts the sediments on Mount Dartmouth are gently dipping and appear to have been transported eastward above the thrust planes, with minimal deformation.

Northeasterly trending faults are evident in the Deschamps Creek-Franklyn Arm area and in Nine Mile Creek. Similar structures were mapped east of Chilko Lake in 1985 and were determined to be relatively young features with little or no lateral movement. These faults are responsible for the uplift and exposure of Triassic rocks in Deschamps Valley. The parallelism of Franklyn Arm, Tredcroft Creek and Girdwood Creek, together with the occurrence of airphoto linears and the orientation of joints in these areas, suggest that these valleys may be underlain by northeasterly faults.

A broad southwesterly plunging synclinal fold, cored by the purple volcanic rocks of Unit 4, dominates the centre of the map area between the two major fault zones. The fold axis trends across Chilko Lake and is seen again to the southeast in younger rocks equivalent to the Taylor Creek Group.

MINERALIZATION

Copper-bearing skarn mineralization has been known on the Daisie property (MI 092N-026) near the head of Franklyn Arm since the early 1920s. A 3-kilometre trail leads to the showings from a cabin at the head of Franklyn Arm. Limestones within the Triassic sediments have been intruded and recrystallized to sugary marbles by quartz diorite stocks of the Coast Plutonic Complex. A fine-grained and moderately altered diorite to quartz-diorite stock truncates the Triassic rocks in Deschamps Creek and a larger stock of coarse-grained, relatively fresh quartz-diorite to granodiorite intrudes Unit 2 volcanics immediately to the east. A dyke of the coarser intrusive cuts the finer grained diorite. Bluffs of banded grey and white marble with moderate skarn development occur within a few hundred metres of the younger intrusive.

Trenches expose pockets of garnet-diopside-calcite-quartz skarn carrying localized concentrations of veinlet to near massive pyrrhotite-chalcopyrite and disseminated scheelite mineralization. Malachite and azurite are common. The strongest mineralization is controlled by fracture zones in the marble up to 1.5 metres wide. Away from these zones the marbles are clean, white and unmineralized. No significant precious metal values have been reported from these skarns.

The Alexis property, overlooking Chilko Lake, covers copper-mercury-arsenic-antimony mineralization in the silicified fractures and pervasive carbonate alteration of the Tchaikazan fault zone. The faults cut the volcanic and sedimentary rocks of Unit 6 and in this area, the fault zone contains numerous discontinuous dioritic dykes and stocks. Silicified veinlets or quartz-calcite vein breccia with a brown ankeritic matrix carry most of the mineralization. Minerals identified include tennantite, azurite, malachite, cinnabar, realgar, stibnite, hematite, aragonite and dickite; these occur sporadically around the property with the copper-mercury mineralization being concentrated at the "Knob showing". Prospecting along the strike of the fault zone led to the discovery of a new zone of similar copper-mercury mineralization 3 kilometres to the southeast and traces of mercury mineralization 1 kilometre to the northwest, extending the length of the mineralized system well beyond that previously reported. In both cases mineralization was located adjacent to intrusive rocks. Preliminary lithogeochemical analyses of samples from the Alexis area indicate widespread anomalous mercury and antimony values whereas arsenic and copper anomalies are more sporadic. Gold values are low, with a single high value of 445 parts per billion in a sample from the new southernmost showing.

The Tchaikazan fault, and parallel faults, were mapped east of Chilko Lake in 1985 and shown to contain anomalous mercury and copper values (McLaren, 1986 a and b). Mineralization at Alexis is probably epithermal, with the mineralizing fluids moving through a structurally prepared conduit system in the volcanic rocks. Heat to drive convecting hydrothermal fluids may have been supplied by the nearby intrusive bodies. Assessment work, including limited shallow drilling, has not yielded significant precious metal assays. Further encouragement from this area may be gained by probing the fault systems to greater depths or by searching along strike for areas of greater intrusive activity with related hydrothermal alteration and mineralization. A white intrusive stock and enclosing gossanous zone is visible 10 kilometres to the north on the north side of Stikelan Pass (Tipper, 1969). Projections of the Tchaikazan fault zone extending through Stikelan Pass immediately adjacent to this stock may represent a worthwhile prospecting target.

No similar mineralization has yet been found along the Stikelan fault zone. However, a portion of the fault zone cuts rhyolitic volcanics of Units 2 and 3 containing disseminations and massive pods of pyrite-pyrrhotite mineralization, with minor amounts of malachite.

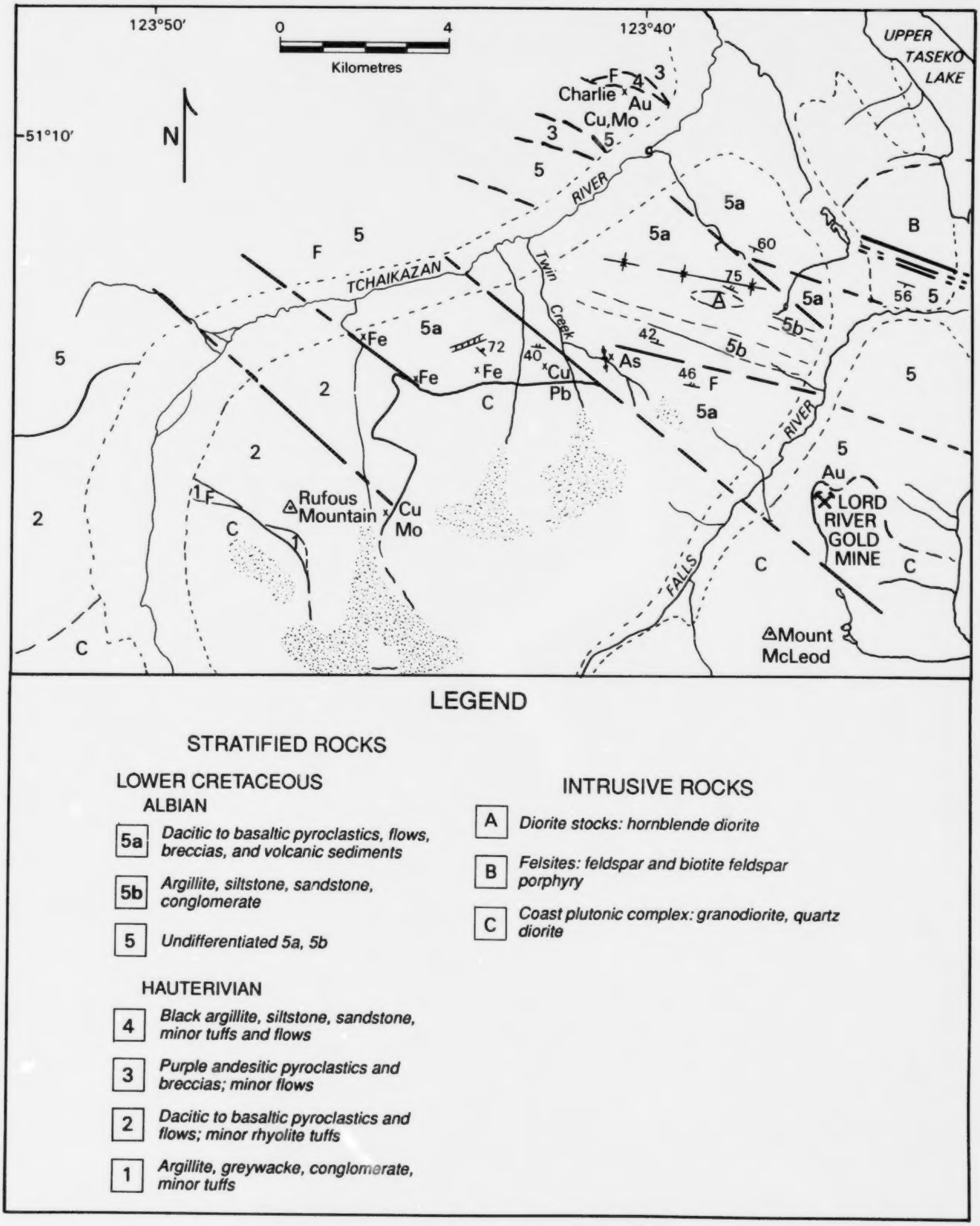
Pyrite and pyrrhotite mineralization in rhyolitic horizons is common in the Hauterivian volcanics observed on both sides of Chilko Lake (McLaren, 1986a). If the suggested correlation with Gambier Group rocks that host the Britannia mine in the southern Coast Mountains is valid, then the potential for volcanogenic massive sulphide deposits in these volcanic units must be considered.

Traces of chalcopyrite and malachite occur on the western periphery of the intrusion at the head of Tredcroft Creek. Pyrite, chalcopyrite and molybdenum mineralization was noted in quartz veins hosted by hornfelsed volcanics just southeast of the toe of Austen Glacier. A broad zone of gossanous hornfelsed volcanics and sediments is present between Austen and Hamilton Glaciers. The entire area between Tredcroft and Austen Glaciers was once covered by a single claim group and a number of other minor copper-molybdenum occurrences have been found.

Unit 4 purple volcanics have undergone brittle fracturing and development of quartz epidote veins over a broad area. North and south of Girdwood Lake copper mineralization was noted in talus. Prospecting upslope revealed epidote alteration zones up to 2 metres wide that contain quartz-carbonate veins and vein breccias carrying native copper and malachite. Prehnite was also identified in vuggy cavities in the veins.

GEOCHEMISTRY

A total of 182 stream sediment samples were collected from an area of approximately 600 square kilometres to the west of Chilko


123°50′
0
4
Kilometres
123°40′
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N
UPPER TASEKO LAKE
Charlie
Au
Cu,Mo
F
4
3
5
5a
5b
B
A
C
2
1
TCHAIKAZAN
RIVER
Twin Creek
FALLS
RIVER
Fe
Cu
Pb
As
Mo
60
75
56
72
40
42
46
Rufous Mountain
LORD RIVER GOLD MINE
Mount McLeod

LEGEND

STRATIFIED ROCKS

LOWER CRETACEOUS

ALBIAN

5a	*Dacitic to basaltic pyroclastics, flows, breccias, and volcanic sediments*
5b	*Argillite, siltstone, sandstone, conglomerate*
5	*Undifferentiated 5a, 5b*

HAUTERIVIAN

4	*Black argillite, siltstone, sandstone, minor tuffs and flows*
3	*Purple andesitic pyroclastics and breccias; minor flows*
2	*Dacitic to basaltic pyroclastics and flows; minor rhyolite tuffs*
1	*Argillite, greywacke, conglomerate, minor tuffs*

INTRUSIVE ROCKS

A	*Diorite stocks: hornblende diorite*
B	*Felsites: feldspar and biotite feldspar porphyry*
C	*Coast plutonic complex: granodiorite, quartz diorite*

Figure 3-10-4. Geology between Tchaikazan and Falls Rivers.

Lake. The density of sampling within the volcanic and sedimentary units is approximately 1 site per 2.5 square kilometres (Figure 3-10-3). All samples will be analysed for 30 elements using an inductively coupled plasma (ICP) technique; for gold by a fire assay and neutron activation analysis; and for mercury using a flameless atomic absorption method.

Rock chip samples were collected from all locations containing mineralization or alteration assemblages potentially related to mineralization. A total of 144 rock samples will be analysed for 14 elements, including base and precious metals and precious metal indicators.

TCHAIKAZAN TO FALLS RIVERS AREA (92O/4)

The area between the Tchaikazan and Falls Rivers was silt sampled but not mapped or prospected during the 1985 season; a short period was spent completing this work in 1986. Figure 3-10-4 outlines the geology mapped and mineral occurrences discovered.

Hauterivian volcanics and sediments, partially mapped in 1985, occur between the upper Tchaikazan River and Discord Creek. This section is entirely volcanic in Discord Valley where it is composed primarily of andesitic lapilli and lithic fragmental tuffs. Hornfelsing by the adjacent Coast Plutonic intrusive is widespread. A fault zone controls a gorge in lower Discord Creek and is marked by a gossanous alteration zone extending high up the slope to the southeast.

Volcanic rocks mapped further to the east are interbedded with fossiliferous sediments and are clearly correlative with the Albian Taylor Creek Group equivalents (Unit 5) mapped in 1985. Similarities between the Hauterivian and Albian volcanics make the contact between these rocks difficult to define. The basal conglomerate of the Albian rocks, seen to the west in 1985, was not located in 1986 and the contact is interpreted to lie along the gossanous fault zone.

The sediments and volcanics of Unit 5 consist of dark grey argillites and siltstones with limy horizons intercalated with andesitic feldspar crystal to lithic fragmental tuffs. Green vesicular flows, with quartz or epidote amygdules that locally carry traces of copper, occur within the tuffs. Beds of reworked epiclastic volcanic material are also common.

These rocks are intruded by a quartz-diorite to granodiorite stock with extensive hornfelsing in adjacent units and a fault truncated eastern contact. Tipper (1978) attributed an Eocene age to this intrusive. Another stock of crowded feldspar porphyry cuts sediments and volcanics 10 kilometres to the east. It is abruptly truncated on the south side by a strong fault zone. This intrusive is related to the Eocene felsites mapped in 1985 (McLaren, 1986 a and b) and by Tipper (1978).

A series of intensely silicified fracture zones, one of which carries considerable realgar mineralization, was found in a broad, drift-covered valley referred to here as Twin Creek valley (Plate 3-10-5). Distinct orange-weathering zones of rubble and outcrop occur 35 metres apart on either side of the creek, while a third isolated zone was noted 150 metres further upstream. Quartz-carbonate veining and vein breccias occur within areas of ankerite-siderite-kaolinite alteration. Realgar, orpiment and traces of cinnabar occur as fine disseminations, in veinlets and as crusts on fracture planes in one zone approximately 4.5 metres in true width. Assays of two channel samples across this zone returned an average of 0.2 per cent arsenic while selected grab samples contain up to 0.4 per cent arsenic; mercury geochemistry ranges from 6 to 18 parts per million. Gold values are low in the mineralized zone, but 100 to 200 parts per billion gold are present in samples taken from the other alteration zones. An anomalous arsenic stream sediment value was determined in this valley in 1985 (McLaren, 1986c) and the valley follows the trace of a major fault, possibly related to mineralization at the Lord River gold mine (MI 92O-045) 6 kilometres to the southeast. Gold mineralization is also known 6 kilometres to the northeast in the Charlie veins (MI 92O-043). The proximity of the Twin Creek arsenic showing to known gold mineralization, a major fault and an intrusive contact suggests this area is highly prospective for precious metal veins.

The periphery of the quartz diorite to grandiorite stock in this area is fractured, quartz veined and mineralized in at least two locations. Copper-lead mineralization occurs on the ridge crest west of Twin Creek while a vein carrying copper-molybdenum mineralization was found in Discord Valley. Stream sediment samples anomalous in gold, arsenic and lead have previously been obtained in this area.

SUMMARY: MINERAL POTENTIAL

The Hauterivian strata west of Chilko Lake accumulated in a marine to subaerial volcanic island arc bounding the Tyaughton trough on the southwest. Uplift of a larger landmass to the west is indicated by siliciclastic deltaic sedimentation during Albian time. Tectonic adjustments and intrusion of the Coast Plutonic Complex led to broad folding, localized areas of imbricate thrust faulting and at least two broad zones of transcurrent faulting. This varied geology offers potential for a diversity of mineral occurrences in the area.

The greatest potential for making new mineral discoveries lies in searching for precious metal epithermal veins in the major structural zones. Brittle fracturing of subaerial volcanic rocks cut by the fault zones has provided the conduit system necessary for fluid migration. Sufficient heat to drive a hydrothermal system may have been provided by intrusive bodies. This is suggested by the close association of the Alexis epithermal mercury-copper-arsenic mineralization with intrusive activity along the Tchaikazan fault zone. Similar relationships between anomalous mercury values and intrusive activity in fault zones were noted in 1985. Prospecting has now documented mercury mineralization over a strike length of 4 kilometres near the the Alexis property. Gold-silver-antimony-arsenic mineralization is known 14 kilometres to the northwest of Alexis at the Morris mine (MI 92N-002) where mineralized quartz veins cut Triassic volcanics and quartz diorite intrusions occur adjacent to the veins. Further mapping and prospecting of structural zones and related intrusives are warrranted in the Chilko Lake region. A more detailed evaluation of the newly discovered realgar-bearing siliceous fault zones overlooking the Tchaikazan Valley is also required.

Gossanous felsic volcanic horizons in Units 2 and 3 suggest a volcanogenic massive sulphide environment in the Hauterivian island arc setting. To date only iron sulphides and traces of copper have been found in these rocks but the proposed correlation with the Gambier Group raises the potential for mineralization analogous to that at Britannia mine. Similar environments and correlations were noted east of Chilko Lake in 1985 (McLaren, 1986a).

Porphyry and skarn mineralization is also known to occur in the Chilko Lake region. The Fish Lake porphyry copper deposit (MI 92O-042) occurs in a similar geologic setting north of Taseko Lakes and porphyry related copper-bearing stockworks are known east of Chilko Lake (McLaren 1986a). Copper-molybdenite veining occurs in the area of Hamilton and Austen Glaciers, but no extensive alteration zones or stockworks have been found. Exploration of the skarn deposits in Deschamps Valley has outlined only limited mineralization to date, however additional altered limestone horizons may exist in the Triassic rocks beneath the broad valley floor.

Prospecting, mapping and geochemical surveys conducted during the past two seasons in the Chilko-Taseko Lakes area continue to define new mineral occurrences, extend known mineralization and highlight zones of higher potential. The discovery of arsenic-bearing veins, adjacent to an arsenic stream sediment anomaly located in the 1985 survey and in an environment favourable for epithermal precious metal mineralization, illustrates the value of following up the geochemical surveys and the potential for making further mineral discoveries.

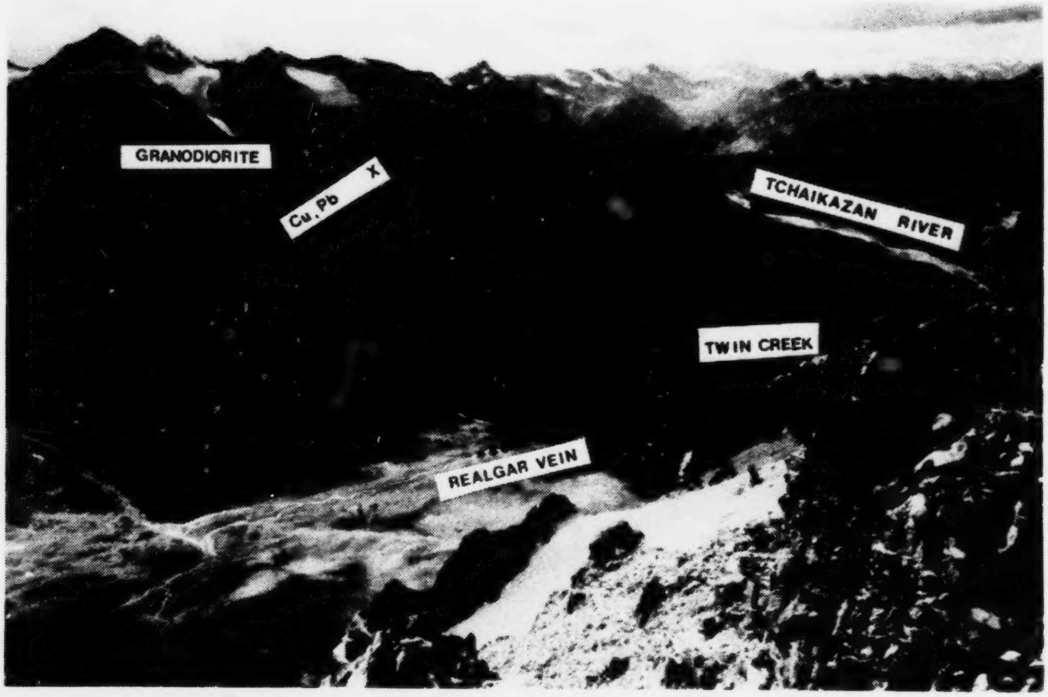

Plate 3-10-5. View of Twin Creek and location of realgar vein. Coast Plutonic Complex lies to the upper left; remaining area comprises Unit 5 sediments and volcanics.

ACKNOWLEDGMENTS

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Industrial Mineral Studies

INDUSTRIAL MINERALS IN SOME TERTIARY BASINS SOUTHERN BRITISH COLUMBIA*

(92H, 92I)

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Geotex Consultants Ltd., Vancouver, British Columbia

INTRODUCTION

This report summarizes results from 72 days of fieldwork investigating the occurrence of industrial minerals, and those aspects of the Tertiary stratigraphy and structure which control the development of industrial minerals, in the Princeton, Tulameen, Merritt-Guichon Creek-Quilchena Creek, McAbee, and Hat Creek basins. The industrial minerals of major interest are bentonite, zeolites and diatomaceous earth, as well as clays for brick and ceramic uses, and materials suitable for concrete aggregates. Laboratory investigations of samples are in progress, but tests of materials relative to ASTM specifications have not yet been started.

STRATIGRAPHY AND STRUCTURE OF THE PRINCETON BASIN AND PLACER MOUNTAIN OUTLIER

The Princeton Basin is a northerly trending trough filled by Eocene volcanic rocks of mainly intermediate composition comprising the Lower Volcanic Formation, and an overlying Eocene sedimentary sequence of sandstone, shale, waterlain rhyolite tephra and coal, up to 2000 metres thick, comprising the Allenby Formation (Rice, 1947; McMechan, 1983). The trough is the site of a major northerly trending half graben bounded on the east by the northerly to north-northeasterly trending Boundary fault (Figure 4-1-1). South of Princeton, northwesterly to westerly trending folds and faults break the half graben into a northern sediment-dominated segment centred on Princeton, and a southern, volcanic-dominated portion centred on Friday Mountain. The Princeton segment contains up to 1370 metres of volcanic rocks overlain by 1600 to 2100 metres of sandstone, tuffaceous sandstone, shale, waterlain rhyolite tephra and coal (McMechan, 1983, page 13). In contrast, the Friday Mountain portion contains at least 1500 metres of volcanic rocks overlain by no more than 100 metres of volcanic conglomerate, sandstone and waterlain rhyolite breccia. A brief examination of the Placer Mountain outlier of Tertiary volcanic rocks shows some 500 metres of medium grey aphanitic flows and overlying porphyritic (plagioclase, hornblende) rhyodacite flows resting on a basement of volcanogenic sediments of the Upper Triassic Nicola Group. Apparently an insufficient thickness of volcanic rocks remains in this outlier to preserve the waterlain acid tephra present in the Friday Mountain segment only 10 kilometres to the northwest.

INDUSTRIAL MINERALS OF THE PRINCETON BASIN

ZEOLITES

The Princeton Basin contains the only bedded zeolite deposits known in southern British Columbia south of latitude 51°N prior to this investigation (Hora and Kwong, 1984), and also the only bentonite deposit with production records. With the exception of the Princeton Ash, all waterlain rhyolite tuff and volcanic breccia layers are zeolitized. They form five distinct tephra lenses which range in thickness from 7 metres, with upper and lower contacts exposed, to more than 22 metres with neither contact exposed, and in length from 400 metres at Bromley Vale to 3500 metres for the Tailings tephra (Figure 4-1-1). The zeolite is heulandite-clinoptilolite which replaces original glass shards in waterlain vitric-crystal (biotite, plagioclase, sanidine, quartz) tuff, and rhyolite glass in volcanic breccia lenses of the Allenby Formation.

The tephra horizons and surrounding sedimentary stratigraphy have been mapped at 1:25 000 scale throughout the basin. Four of the horizons have been sampled in detail at 0.9-metre intervals across their exposed thicknesses at selected localities. They are briefly described following.

The Sunday Creek tephra is the only zeolitized horizon in the Friday Mountain portion of the basin; it lies within 100 metres of the base of the Allenby Formation. The tephra is mainly a fine (1 to 4-centimetre) rhyolite breccia with a vitric-crystal (biotite, feldspar, quartz) matrix and a few per cent subangular andesite clasts up to 5 centimetres in diameter. Although unbedded to crudely bedded, it contains fragments of wood up to 50 centimetres long which indicate that it is waterlain. The breccia outcrops over a distance of up to 500 metres south of the fork of Sunday Creek, in a 5-metre-high roadcut on the west side of Highway 3. The only other exposures are in the south fork of Sunday Creek downstream from Highway 3; the creek twice intersects the tephra which outlines an open, gently northerly plunging syncline. In a section sampled in detail about 100 metres downstream from Highway 3, the creek exposes a volcanic pebble to cobble conglomerate underlying a section of tephra at least 30 metres thick which grades into an overlying brownish weathering sandstone (Figure 4-1-2a). The tephra has a strike length of 1300 metres with both ends passing beneath drift.

In the Princeton portion of the basin, Asp Creek tephra is the stratigraphically lowest zeolitized horizon that has been sampled in detail. It lies about 30 metres below the unzeolitized Princeton Ash and is exposed on the highway to Tulameen at the northwest end of the single-lane bridge across Tulameen River within Princeton town limits. The tephra contains scattered plant fragments and consists of bedded, white ash with intercalated layers of vitric-crystal (biotite, plagioclase, sanidine, quartz) tuff. Because neither the top nor bottom contacts are exposed at this locality, the tephra was sampled in detail from cliffs on the right bank of Asp Creek about 500 metres upstream from its junction with Tulameen River (Figure 4-1-2b). There the tephra is 7.3 metres thick, overlies a fine-grained biotite-bearing sandstone and underlies a carbonaceous shale. The strike length of the tephra is about 1000 metres with both ends covered by drift, but with an eastern extension likely.

Tailings tephra is the most extensive zeolitized horizon in the Princeton Basin. It is exposed in a roadcut on the northwest side of Highway 3, 600 metres east of a side-road up Bromley Creek and 100 metres northeast of an operating gravel pit (Figure 4-1-2c). A few exposures lie up to 900 metres west of the highway and several lie up to 2200 metres to the east. These outcrops all lie on the north limb of a westerly trending and gently plunging syncline. About 500 metres to the south, Tailings tephra outcrops on the south limb of the syncline from the left bank of Similkameen River to the former

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

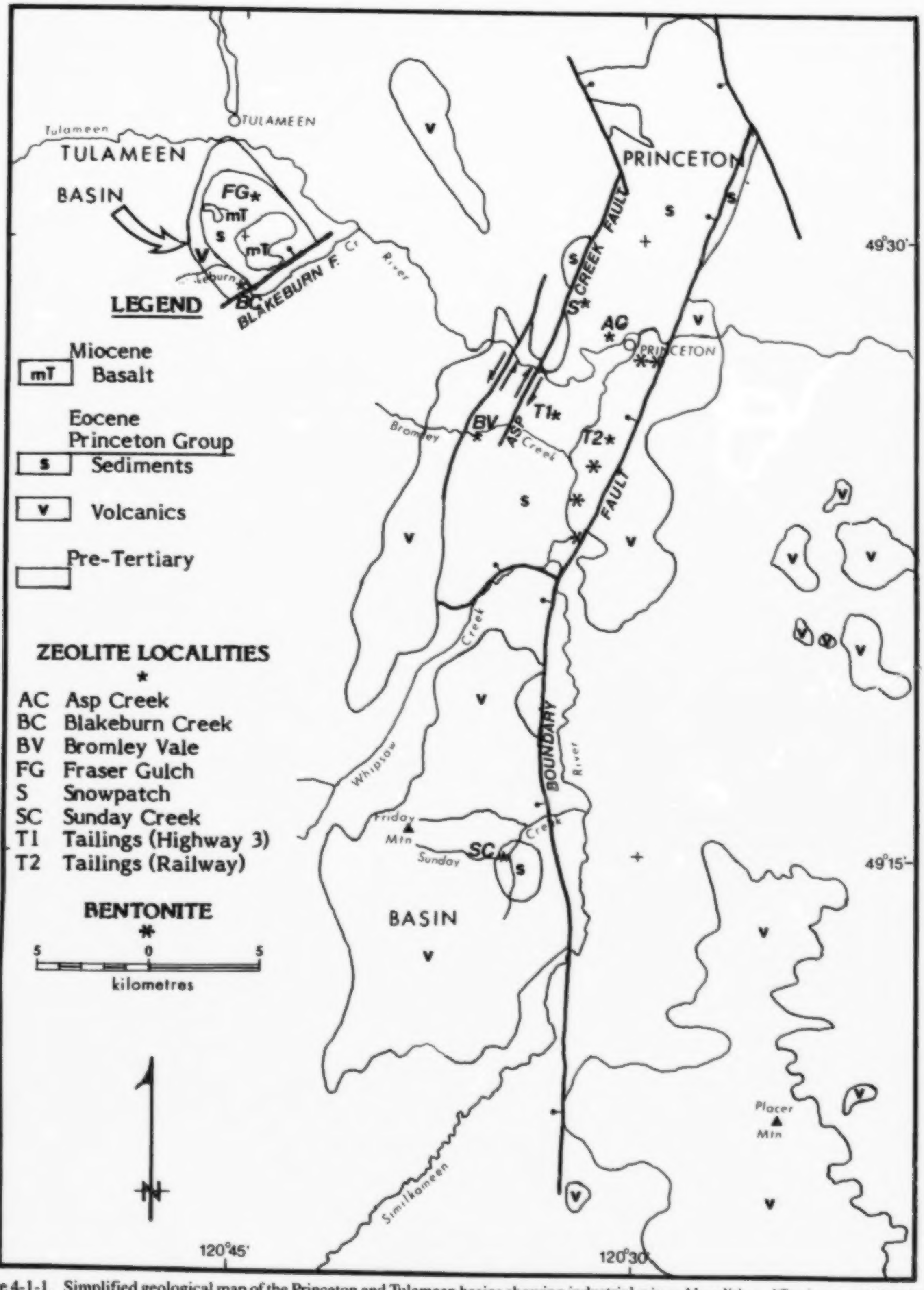
TULAMEEN
Tulameen
TULAMEEN
BASIN
FG
mT
s
V
BC
BLAKEBURN F.
Blakeburn Cr.
River
LEGEND
Miocene
mT Basalt
Eocene
Princeton Group
s Sediments
v Volcanics
Pre-Tertiary
ZEOLITE LOCALITIES
*
AC Asp Creek
BC Blakeburn Creek
BV Bromley Vale
FG Fraser Gulch
S Snowpatch
SC Sunday Creek
T1 Tailings (Highway 3)
T2 Tailings (Railway)
BENTONITE
5
0
5
kilometres
N
PRINCETON
PRINCETON
CREEK FAULT
S
AC
BV
T1
T2
ASP
Bromley
Creek
FAULT
BOUNDARY
River
Whipsaw
Creek
Friday Mtn
Sunday
Creek
SC
BASIN
Similkameen
Placer Mtn
49°30'
49°15'
120°45'
120°30'

Figure 4-1-1. Simplified geological map of the Princeton and Tulameen basins showing industrial mineral localities. [Geology modified from Church and Brasnet (1983), McMechan (1983) and Monger (unpublished data)].

Copper Mountain railway grade. Along the grade, a section sampled in detail consists of a 4-metre thickness of vitric-crystal (biotite, feldspar, quartz) tuff overlain by 4.2 metres of mainly vitric rhyolite tuff. Neither the top nor bottom contacts of the zeolitized horizon are exposed. The thick montmorillonite-bearing vitric-crystal tuff layers with less than 40 per cent zeolite, surrounding a 1-metre-thick, fine rhyolite breccia with 40 to 60 per cent zeolite, as exposed in the highway section (Z.D. Hora, personal communication, 1986), are absent in the railway section. The presence of differing rock types in the two sections indicates that horizontal facies changes are present and these may have an affect on the extent of zeolitization.

A 22-metre thickness of Bromley Vale rhyolite tephra is exposed in Bromley Creek upstream from the portal to Bromley Vale No. 1 mine. It contains fragments of carbonized wood and plants (Figure 4-1-2d). Downstream, the easterly flowing creek crosses 9 metres of fine, white to cream-coloured rhyolite breccia overlain by 13 metres of white to light grey vitric-crystal (biotite, feldspar, quartz) bedded tuff and a thin, dark grey silicified (?) tuff. Neither the top nor bottom contacts are exposed and to the south very thick overburden mantles any possible extension. The tephra does not reappear to the north perhaps because of truncation by Asp Creek fault. If Asp Creek fault has a right-lateral strike-slip displacement of about 1200 metres, then Bromley Vale tephra should correlate with Tailings tephra.

Snowpatch tephra is exposed at 2825 feet (861 metres) elevation 2300 metres up the road to Snowpatch ski area from the Princeton-Tulameen Highway (Figure 4-1-1). A rockcut on the south side of the road exposes about 5 metres of yellow-ochre-weathering, coarse tuffaceous sandstone composed mainly of quartz, feldspar and biotite grains. Although neither the top nor bottom contacts are exposed, the zeolitized horizon is probably not much thicker than 5 metres. About 800 metres to the south-southwest, at 3100 feet (945 metres) elevation and east of a powerline, a dip slope exposes a 30-metre width of white-weathering vitric-crystal tuff. The strike length of the tephra horizon is 2400 metres with both ends passing under drift.

BENTONITE

Bentonite is widespread throughout the Princeton portion of the Princeton Basin, usually occurring in the shale and coal-rich sections of the stratigraphy in layers up to 2 metres thick (McMechan, 1983, page 19). Because bentonite outcrops slump shortly after exposure, only a few localities were sampled. A 4.3-metre-thick bentonite seam was exposed on the old Copper Mountain railway grade just south of the switchback about 2.4 kilometres south of Princeton, and a 1.9-metre-thick seam was exposed about 1600 metres to the east of the railway exposure (Spence, 1924, pages 9-10; Cummings and McCammon, 1952, pages 33-34). On the same railway grade, about 6 kilometres south of Princeton, a seam,

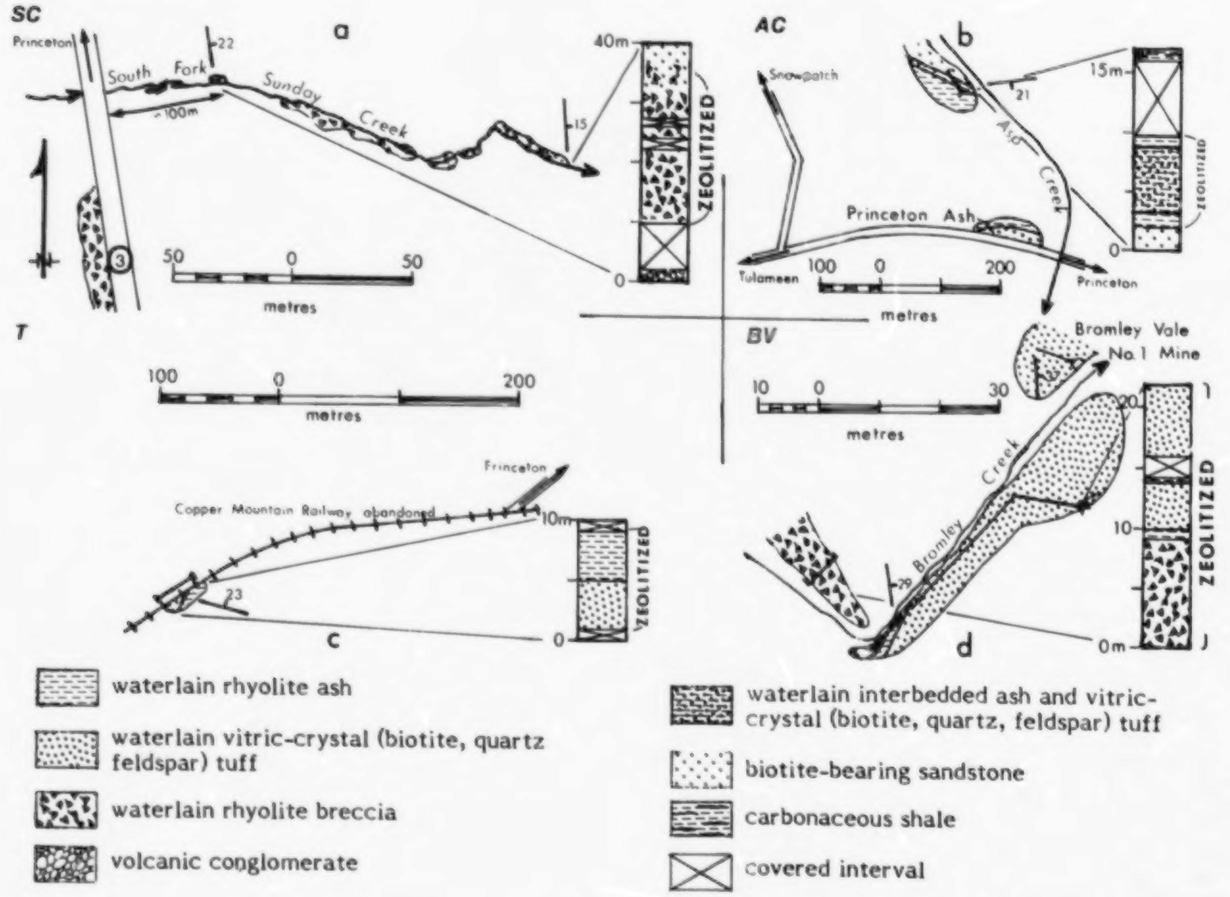
SC
Princeton
South Fork
Sunday Creek
22
~100m
15
a
40m
0
ZEOLITIZED
50
0
50
metres
3
T
100
0
200
metres
Princeton
Copper Mountain Railway abandoned
10m
0
23
ZEOLITIZED
c
AC
Snowpatch
b
21
Asp Creek
15m
0
ZEOLITIZED
Princeton Ash
Tulameen
100
0
200
Princeton
metres
BV
Bromley Vale No. 1 Mine
10
0
30
metres
Bromley Creek
29
20
10
0m
ZEOLITIZED
d
waterlain rhyolite ash
waterlain vitric-crystal (biotite, quartz feldspar) tuff
waterlain rhyolite breccia
volcanic conglomerate
waterlain interbedded ash and vitric-crystal (biotite, quartz, feldspar) tuff
biotite-bearing sandstone
carbonaceous shale
covered interval

Figure 4-1-2. Geological sketch maps of sampled localities of zeolitized tephra in the Princeton Basin.

reported by Cummings and McCammon to lie 8 kilometres south of Princeton (1952, page 34), has been freshly exposed and consists of a metre of carbonaceous shale underlying a 4.9-metre-thick sequence of bentonitic siltstone, shale and bentonite, capped by 1 metre of fine sandstone. About 400 metres east of Similkameen River and 7.2 kilometres south-southwest of Princeton, McMechan (1983, pages 19-21) reported a sandy bentonite 9 metres thick which was encountered at shallow depths in boreholes. Two kilometres downstream from the mouth of Whipsaw Creek, the slumped right bank of Similkameen River exposes a 20-metre-thick sequence of siltstone, bentonitic siltstone and bentonite which is part of the highest stratigraphy exposed in the basin. Shaw (1952, page 8) mentioned that bentonite occurs in two unspecified localities in seams about 4.6 metres thick. These are probably two of the seams observed by earlier workers.

With the exception of Sunday Creek tephra, all of the industrial mineral localities briefly described lie within 8 kilometres of the Canadian Pacific Railway which passes through Princeton.

STRATIGRAPHY AND STRUCTURE OF THE TULAMEEN BASIN

The Tulameen Basin preserves 1400 metres of Eocene volcanic and sedimentary rocks which overlie the Upper Triassic Nicola Group and underlie two remnants of Miocene Plateau Basalt (Church and Brasnet, 1983). Up to 500 metres of grey sparsely porphyritic (hornblende) dacite flows and locally rhyodacite to rhyolite flows and waterlain tuffs of the Lower Volcanic Formation underlie sedimentary rocks of the Allenby Formation. Along Blakeburn Creek, the passage from volcanic to the overlying sedimentary rocks is transitional as breccias pass upwards into crudely bedded breccia and tuffaceous wacke (Figure 4-1-1). The lower part of the sedimentary sequence grades laterally from breccia and tuffaceous sandstone in the southwest to arkose in the east. A medial section of shale and coal, and an upper section of mainly sandstone and granule conglomerate with minor acid tephra, complete a 790-metre thickness of sedimentary rocks. The 90-metre-thick shale and coal section is sparsely exposed in roadcuts; the 590-metre-thick upper sandstone-conglomerate section is poorly exposed. Church and Brasnet (1983, page 49) noted that the frequency of felsic volcanic rocks increases stratigraphically upwards to where rhyolite airfall tephra forms 12 thin layers in the upper part of the coal measures. The basin is a remnant of a southeasterly plunging syncline which has been truncated on its southeast side by Blakeburn fault.

INDUSTRIAL MINERALS IN THE TULAMEEN BASIN

Waterlain acid tephras of the Lower Volcanic Formation and the lower and middle sections of the Allenby Formation are suitable host rocks for the development of zeolites. Pevear *et al*. (1980) noted that most of the tephra layers consist of angular quartz, biotite and sanidine in a finer matrix of quartz, clay and other minerals. In the northern part of the basin, relict glass shards are altered to quartz, regularly interstratified illite-smectite and minor heulandite-clinoptilolite. Preliminary X-ray diffraction results from samples of waterlain acid tephra, collected during the present investigation, show that acid tephra of the Lower Volcanic Formation is locally replaced by laumontite on the southwestern edge of the basin at locality BC (UTM coordinates FK0663200mE, FK5483100mN) (Figure 4-1-1). Although the lower part of the sedimentary section is volcaniclastic in the southwest corner of the basin, the rocks apparently do not contain zeolites. In contrast to the thin acid tephra layers in the middle shale-coal section, which contain only minor heulandite-clinoptilolite, the upper sandstone section contains a heulandite-clinoptilolite-rich vitric-crystal (biotite, quartz, feldspar) tuff that is at least 3 metres thick and can be followed for about 100 metres southeastwards from an exposure on a four-wheel-drive track at locality FG (FK0663300mE, FK5486700mN). The southwesterly dipping waterlain tuff lies within a sandstone-granule conglomerate section and passes under drift along strike. A concentration of angular acid tephra float, containing heulandite-clinoptilolite, lies beside a barbed-wire fence at FK0662100mE, FK5486100mN.

Bentonite layers up to a metre thick are part of the middle shale and coal section. Cation exchange analyses of the bentonites indicate that calcium and magnesium are the major exchangeable cations (Peaver *et al.*, 1980). No bentonite layers outcrop and the sparse exposures do not allow a proper assessment of the zeolite potential. All industrial mineral localities lie within 6 kilometres of the Canadian Pacific Railway at Tulameen or Coalmont.

STRATIGRAPHY AND STRUCTURE OF THE MERRITT-QUILCHENA CREEK-GUICHON CREEK BASIN

Tertiary rocks in the Merritt-Quilchena Creek-Guichon Creek areas are dominantly clastic sediments of the Coldwater Formation. Eocene volcanic rocks of the Kamloops Group underlie a small area southwest of Merritt and west of Lower Nicola (Figure 4-1-3). Outcrops of the Coldwater Formation are so sparse that only local stratigraphic sections up to a few hundred metres in thickness have been measured in the coal-mining area southwest of Merritt. Even Cockfield's (1948, page 33) suggested stratigraphic order of sediments of the Coldwater Formation underlying volcanic rocks of the Kamloops Group seems unlikely. As Ells (1905), White (1947) and Cockfield (1948) observed, sandstone-rich sediments of the Coldwater Formation form southeasterly plunging, open to tight upright folds southwest of Merritt. The southwesternmost sediments occupy the core of a northeasterly overturned syncline and the volcanics of the Kamloops Group, bordering the sediments on the southwest, are a lower rather than a higher stratigraphic unit. In Quilchena Valley, mainly pebble conglomerate and sandstone, with minor shale and rare coal and bentonite, comprise a gently northeasterly dipping sequence unconformably overlying the Nicola Group, and dipping into a northerly trending fault on the east (Monger, 1982). In Guichon Valley, a single area of outcrop, 6 kilometres north of Lower Nicola, exposes about 500 metres of shale, claystone, bentonite and sandstone which dips gently northeastward into the Guichon Creek fault. Northwest of Lower Nicola, Tertiary volcanics probably pass northwards and upwards into sediments of the Coldwater Formation which lie beneath the drift-covered valley floor. This succession lies between the Guichon Creek fault on the east and an unnamed fault splay on the west (Figure 4-1-3).

INDUSTRIAL MINERALS IN MERRITT-QUILCHENA CREEK-GUICHON CREEK BASIN

The Guichon and Quilchena Valleys each have bentonite localities. In the Guichon Valley (GC, Figure 4-1-3) roadcuts on the road to Logan Lake, between 5.3 and 6.7 kilometres north of Highway 8, partly expose a section of claystone, shale, and friable sandstone which outcrops more completely east of the road in the beds of the first two intermittent streams south of Morgan Creek. West of the road, bulldozer trenches and roads expose shale and slumped bentonite. In the Quilchena Valley (QC, Figure 4-1-3) bentonite and slumped bentonite, possibly 8 metres thick, outcrop in a gully at 2400 feet (732 metres) elevation east of a caved adit, just above the Quilchena Creek road. The adit and shallow trenches, which expose shale, coal and bentonite, lie 3.5 kilometres up Quilchena Creek road from Highway 5. In the Guichon Valley the bentonite locality lies less than 7 kilometres from the Canadian

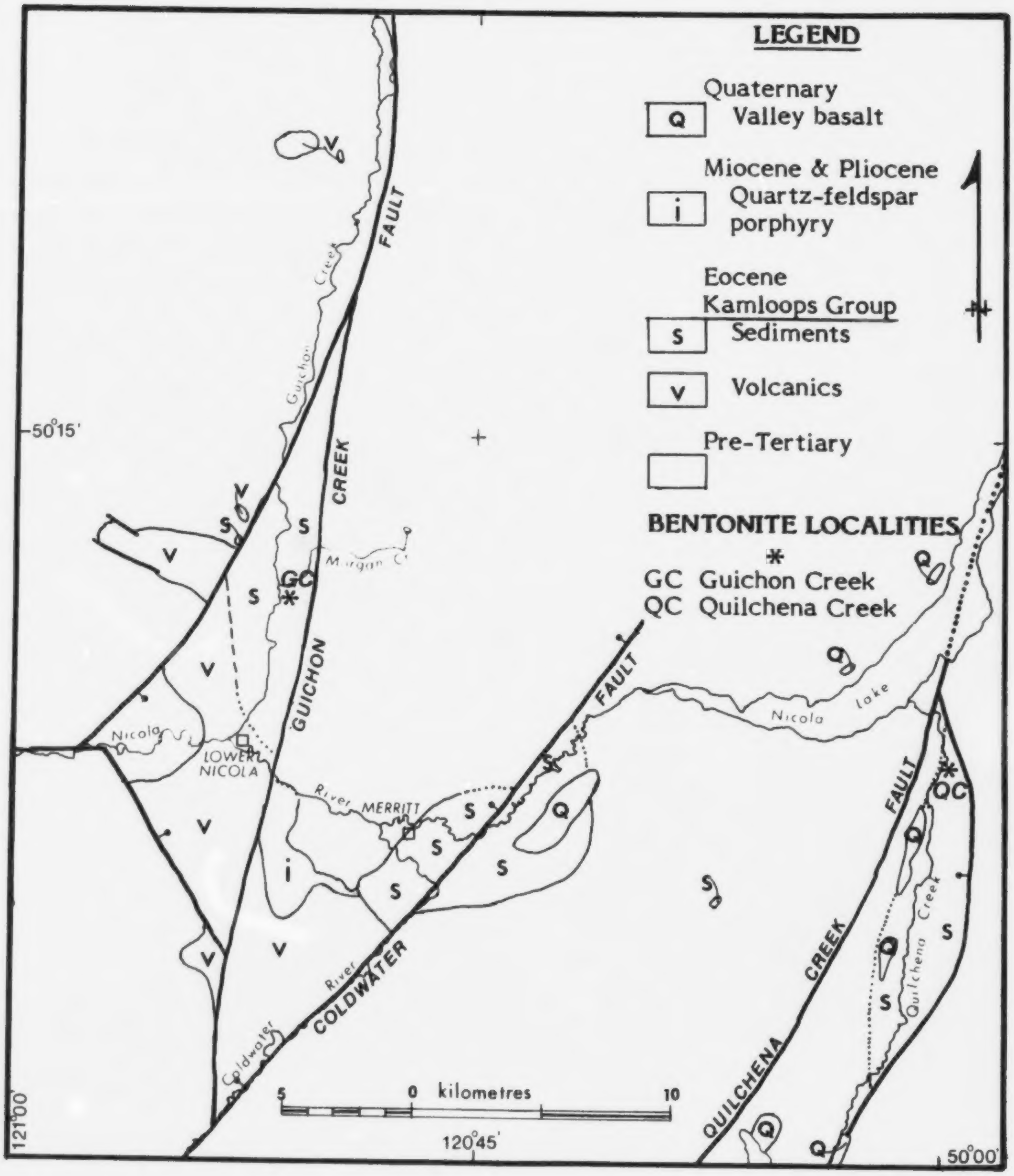
LEGEND
Quaternary
Q Valley basalt
Miocene & Pliocene
i Quartz-feldspar porphyry
Eocene
Kamloops Group
S Sediments
V Volcanics
Pre-Tertiary
BENTONITE LOCALITIES
*
GC Guichon Creek
QC Quilchena Creek
GUICHON CREEK FAULT
COLDWATER FAULT
QUILCHENA CREEK FAULT
Guichon Creek
Morgan Cr.
Nicola
LOWER NICOLA
River
MERRITT
Nicola Lake
Quilchena Creek
Coldwater River
50°15′
50°00′
121°00′
120°45′
5 0 kilometres 10

Figure 4-1-3. Simplified geological map of the Merritt-Guichon Creek-Quilchena Creek area showing industrial mineral localities [geology modified from White (1947), Preto (1979) and Monger (1982)].

Pacific Railway at Coutlee or Coyle. Bentonite occurrences in Quilchena Valley are about 27 kilometres from the railway at Merritt. Although the Coldwater Formation occupies the same stratigraphic position as the zeolitized tuffs of the Allenby Formation in the Princeton and Tulameen Basins, waterlain acid tephra, the most suitable host rock for zeolites, is unreported in the Merritt-Quilchena Creek-Guichon Creek basin. The lack of outcrop hinders an assessment of the industrial mineral potential and further investigation depends upon a planned examination of drill cores from the region.

STRATIGRAPHY AND STRUCTURE OF THE CACHE CREEK-McABEE AREA

North of the Trans-Canada Highway between McAbee and Cache Creek, Tertiary volcanic and minor sedimentary rocks overlie either volcanic rocks of the Nicola Group or dark grey slate of the Ashcroft Formation on an unconformity that has up to 250 metres of relief at the west end of the Cache Creek Hills (Figure 4-1-4). Medium grey aphanitic flows and flow breccias, and grey porphyritic (plagio-

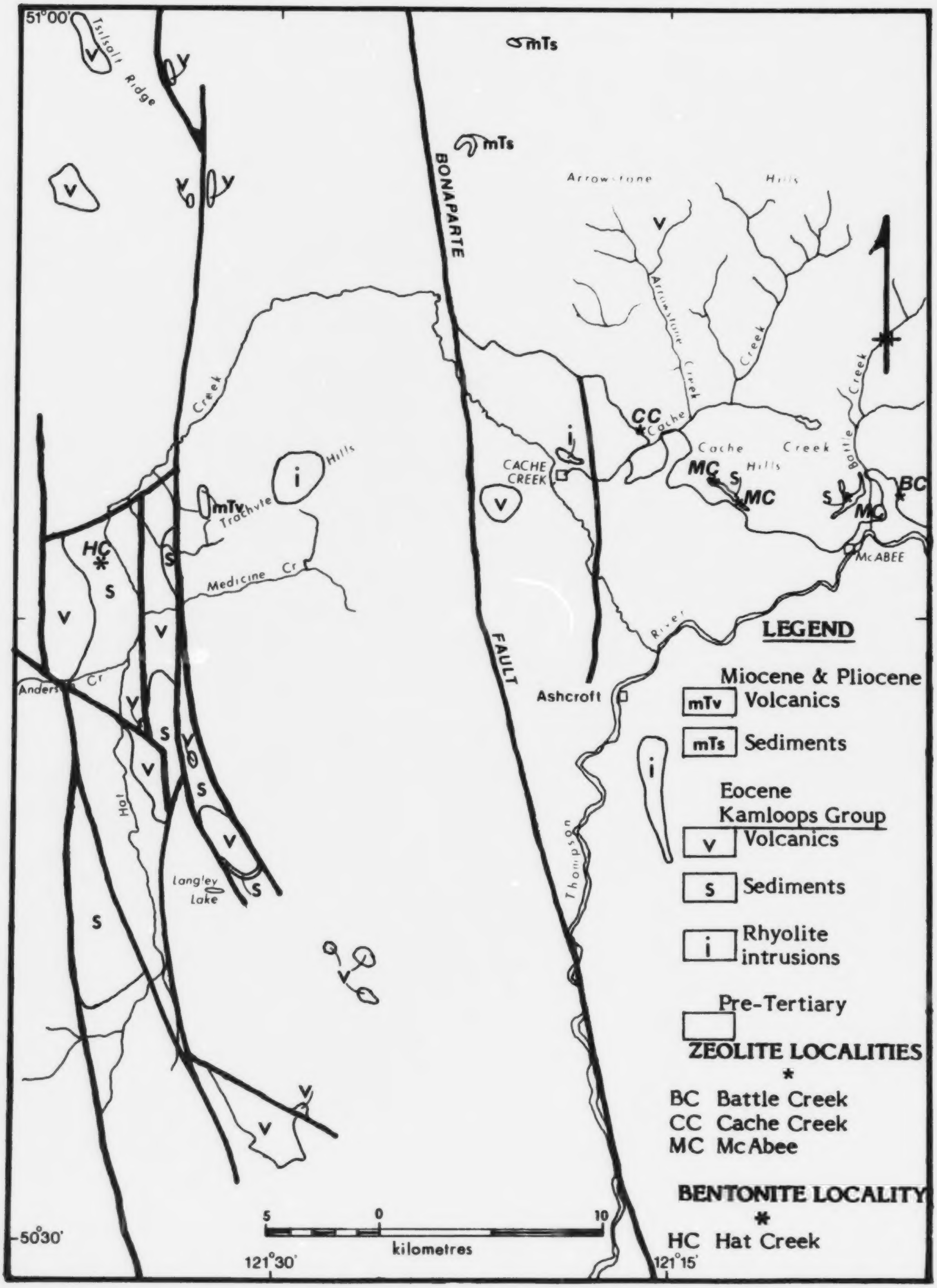
51°00'
Tsilsolt Ridge
V
Y
mTs
mTs
BONAPARTE
FAULT
Arrowstone Hills
Arrowstone Creek
Creek
Creek
Battle Creek
CC
Cache
Cache Creek Hills
MC
S
MC
S
MC
BC
McABEE
i
CACHE CREEK
V
Hills
i
mTv
Trachyte
HC
S
Medicine Cr
V
V
River
Anderson Cr
Y
S
V
S
Hat
V
Langley Lake
S
S
Ashcroft
Thompson
i
LEGEND
Miocene & Pliocene
mTv Volcanics
mTs Sediments
Eocene
Kamloops Group
V Volcanics
S Sediments
i Rhyolite intrusions
Pre-Tertiary
ZEOLITE LOCALITIES
*
BC Battle Creek
CC Cache Creek
MC McAbee
BENTONITE LOCALITY
*
HC Hat Creek
5
0
10
kilometres
50°30'
121°30'
121°15'

Figure 4-1-4. Simplified geological map of the McAbee-Cache Creek-Hat Creek area showing industrial mineral localities [geology modified from Church (1977), Ewing (1981) and Monger (1982)].

clase, hornblende) andesite flows of the Kamloops Group, up to a few hundred metres in thickness, underlie two lenses of sedimentary rocks. The western lens, called the McAbee sediments by Hills (1965, page 23), is 2 kilometres long, up to 30 metres thick, and outcrops in the cliffs 5 or more kilometres west of the Trans-Canada Highway culvert across Battle Creek. The lower 24 metres of section is a pebble to cobble conglomerate which underlies 6 metres of shale, carbonaceous shale, bentonite, and minor white tuffaceous siltstone. A medium grey aphanitic volcanic breccia overlies the McAbee sediments.

The second sedimentary lens, about 2 kilometres long and up to 150 metres thick, outcrops in the cliffs less than a kilometre northwest of the culvert across Battle Creek. It also contains a basal polymictic pebble to cobble conglomerate up to 30 metres thick that passes upwards into white-weathering siltstone and shale. Locally the uppermost 6 to 10 metres is a white-weathering rhyolite tuff that interfingers with the andesite lahar overlying the sediments.

White-weathering, aphanitic rhyolite dykes intrude slates of the Ashcroft Formation at the west end of Cache Creek Hills. The dykes do not intrude the Tertiary succession. Just north of the Cache Creek village limits, a body of white aphanitic rhyolite and rhyolite breccia may intrude greenstone of the Cache Creek Group. In the Trachyte Hills, 12 kilometres west of Cache Creek, a massive aphanitic rhyolite underlies a roughly circular area, 2 kilometres in diameter, and either lies on or intrudes unnamed Lower to Middle Cretaceous sediments (Church, 1977, page G109; Monger, 1982). A 6-kilometre-long body of porphyritic (biotite, hornblende, quartz, feldspar) rhyolite, which Drysdale called the Ashcroft rhyolite porphyry, outcrops south-southeast of Ashcroft and 13 kilometres from Cache Creek. Although long believed to be part of the Kamloops Group volcanic suite and to rest on deformed shales of the Ashcroft Formation (Drysdale, 1914, page 141; Duffell and McTaggart, 1952, page 67; Monger, 1982), the rhyolite locally has vertical or outward dipping contacts and shales within a metre of its margin are contact metamorphosed. All of these occurrences of rhyolite are probably intrusive into pre-Eocene but not Eocene rocks, suggesting that the earliest phase of vulcanism in the Kamloops Group was acidic.

White, waterlain, crystal-rich (biotite, hornblende, quartz, feldspar) vitric tuff locally forms thin basal lenses of Eocene sediments, up to 15 metres thick, immediately overlying grey slate of the Ashcroft Formation at and near the west end of Cache Creek Hills at FM0624400mE, FM5630400mN, and at FM0621700mE, FM5632000mN. The tuff nonconformably overlies the Guichon Creek batholith 1.5 kilometres east-northeast of the Trans-Canada Highway culvert across Battle Creek at FM0633700mE, FM5629400mN.

As the names Arrowstone Creek and Arrowstone Hills imply, the area has long been known to the Indians as a source of glassy rocks suitable for the making of stone implements. In addition, a volcanic remnant of the Kamloops Group on Tsilsalt Ridge contains obsidian (J.W.H. Monger, personal communication, 1986).

Dips are gentle in the Cache Creek-McAbee area, usually less than 20 degrees, and the irregularity of the Tertiary unconformity results from a high paleorelief and not from subsequent deformation.

INDUSTRIAL MINERALS OF THE CACHE CREEK-McABEE AREA

The basal tuffaceous lenses of the Eocene succession are commonly zeolitized with heulandite-clinoptilolite replacing original vitric fragments. North of Cache Creek and near the west end of the Cache Creek Hills (FM0621700mE, FM5632000mN), all nine samples taken from a 6-metre-thick section of bedded vitric-crystal (biotite, hornblende, quartz, feldspar) rhyolite tuff contain heulandite-clinoptilolite (CC, Figure 4-1-4). Neither the top nor bottom of this section of basal Tertiary tuff outcrops and within a hundred metres along strike it passes beneath drift. At 1900 feet (579 metres) elevation and 1.5 kilometres east-northeast of the Trans-Canada Highway culvert over Battle Creek (FM0633700mE, FM5629400mN), a minimum thickness of 6 metres of bedded vitric-crystal (biotite, hornblende, quartz, feldspar) tuff with heulandite-clinoptilolite overlies a sedimentary breccia composed of angular fragments derived from the underlying Guichon intrusion (BC, Figure 4-1-4). At FM0624400mE, FM5630400mN, a single sample from a lens of the same basal tuffaceous sandstone is not zeolitized, but poor exposures prevented proper sampling.

Within a few hundred metres above the base of the volcanic-rich Eocene section, tuffaceous sediments of the two lenses north of McAbee are commonly zeolitized (MC, Figure 4-1-4). Shale, claystone and siltstone, containing zeolitized vitric-crystal tuffs, comprise the upper 10 to 70 metres of the lenses. The bedded tuffs range in thickness from less than a metre to more than 5 metres and in rock type from heulandite-clinoptilolite-bearing vitric-crystal (biotite, hornblende, quartz, feldspar) to finely laminated vitric tuffs. In the latter, mineral assemblages range from dominantly tridymite-cristobalite through mixtures containing some of heulandite-clinoptilolite, kaolinite, montmorillonite, feldspar and quartz, to essentially pure heulandite-clinoptilolite. The lenses have not been mapped or sampled in detail.

Bentonite-bearing rocks are rare in the area. North of McAbee, the upper 10 metres of the western end of the western sedimentary lens contains friable bentonite-bearing sandstone and siltstone.

All zeolite and bentonite localities lie within 11 kilometres of the Canadian National Railway at McAbee or Ashcroft and are within 3 kilometres of the Trans-Canada Highway.

Sources of glassy volcanic rocks, potentially suitable for pozzolan, occur within the watershed of Arrowstone Creek and on Tsilsalt Ridge.

STRATIGRAPHY AND STRUCTURE OF HAT CREEK BASIN

The Hat Creek basin consists of two northerly plunging synclines and an intervening faulted anticline, preserved within a northerly trending system of easterly dipping, reverse and strike-slip faults (Figure 4-1-4). The 1500 or more metres of Late Eocene (Rouse, 1977) basin-fill consists of over 1000 metres of sediments capped by 400 to 600 metres of acid and intermediate volcanic rocks. According to Church (1977), the lowest unit consists of coal with intercalations of siltstone, conglomeratic sandstone and thin bentonite layers. Overlying the uppermost coal is a monotonous siltstone-claystone sequence that is up to 600 metres thick. For surface mapping of the very sparse outcrops in the Hat Creek Valley, the author presently prefers Monger's (1982) nomenclature and has combined both sedimentary units into the "Hat Creek Beds". Although the "Hat Creek Beds" are over 1000 metres thick in the central part of the basin, they thin dramatically to the southeast near Langley Lake where less than 100 metres lies between the basement of Cache Creek limestone and the overlying Eocene volcanic rocks. The lowest of the overlying volcanic units is rhyolitic in composition, and ranges from flows, through volcanic breccia and unbedded tuff to waterlain tuffaceous sediments. The complete range in rock types outcrops in an unnamed gully 5 kilometres north of Medicine Creek where the unit is 500 metres thick. From there the unit outcrops discontinuously for 14 kilometres southward along the east side of the Hat Creek Valley and in widely scattered locations on the west side. Aphanitic grey to maroon volcanic breccia and lahar of intermediate composition interfingers with and overlies the rhyolite flows and tephra on both sides of the valley. The highest volcanic unit consists of grey aphanitic flows of latite and dacite which outcrop on both sides of the valley. All but the lowest unit of the succession outcrop on the western limb of a faulted anticline exposed in an unnamed creek about 3 kilometres north of Medicine Creek.

Although the Hat Creek basin has been described as a graben, structural data collected during surface mapping appear to conflict with this interpretation. These data are: (1) in map pattern, the faults within and bounding the Eocene rocks at Hat Creek are convex to the west; (2) Tertiary strata in the easternmost fault panel in Hat Creek Valley dip from steeply westward through the vertical to overturned to the northeast; (3) a few small faults at 3450 feet (1052 metres) elevation in an unnamed creek 3 kilometres north of Medicine Creek are easterly dipping reverse faults and; (4) roadcuts along Highway 12, exposing the easternmost fault zone bounding the basin, show oblique-slip faults with strike-slip as the dominant component of movement. These observations seem more compatible with a northerly trending system of easterly dipping reverse faults developed either synchronously with, or followed by, strike-slip movement on the northerly trending faults and a northwesterly trending fault cutting the Eocene rocks east of Anderson River. A northeasterly striking fault of unknown displacement forms the northern limit of Eocene rocks in the Hat Creek Valley.

INDUSTRIAL MINERALS OF HAT CREEK

Bentonite is widespread and the main industrial mineral contained in the "Hat Creek Beds" and overlying acid volcanic unit. Montmorillonite, the major clay mineral component of bentonite, is widely distributed within the coal layers and in the overlying siltstone-claystone sequence (Campbell *et al.*, 1977). Bentonitic siltstone and claystone outcrop in a trench 9 metres deep at EM0597600mE, EM5625200mN (HC, Figure 4-1-4), but the hummocky topography, disturbed drainage pattern, and lack of outcrop on many of the lower slopes on the west side of Hat Creek Valley attest to the presence of bentonite in the subcrop. A detailed investigation of the bentonite potential in the Hat Creek Valley awaits a planned examination of B.C. Hydro's drill logs and core.

An X-ray diffraction examination of 31 samples of acid tephra from Hat Creek Valley shows only a trace of possible heulandite-clinoptilolite in four samples. The zeolite potential is low because the most suitable host rock is mainly altered to montmorillonite.

At the north end of the valley, a trench 200 metres long, oriented along the dip direction of the moderate east-northeasterly dipping beds, exposes a zone of burnt coal and baked sediments which is estimated to affect a zone measuring 200 by 700 metres (Church *et al.*, 1979). The baked sediments have been tested for use as a pozzolan, but they do not meet the ASTM criteria (Z.D. Hora, personal communication, 1986). Another burnt zone outcrops in a few roadcuts at EM0598600mE, EM5611700mN, but has not been tested.

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GEOLOGY OF THE ROCK CANYON CREEK FLUORITE/RARE EARTH ELEMENT SHOWING SOUTHERN ROCKY MOUNTAINS*

(82J/3E)

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INTRODUCTION

The Rock Canyon Creek showing (Candy and Deep Purple claims) is hosted by Middle Devonian carbonate rocks in the southern Rocky Mountains of British Columbia. The property lies near the headwaters of Rock Canyon Creek (Figure 4-2-1) in the eastern White River drainage, approximately 40 kilometres east of the town of Canal Flats. It is accessible by conventional vehicles along the White River and Canyon Creek forestry roads, which join Highway 3A, 2 kilometres south of Canal Flats. The main mineralized zone lies between the 1525 and 2000-metre elevations in a valley that has been burnt over and subsequently been logged. Access is excellent, but exposure poor due to thick glacial drift cover.

The Rock Canyon Creek prospect was discovered in 1977 during a regional exploration program carried out by Riocanex (then Rio Tinto Canadian Exploration Ltd.), in search of Mississippi Valley-type lead-zinc mineralization (C. Graf, personal communication, 1986).

Between 1977 and 1979, mapping, soil and rock geochemistry and trenching were done to assess the fluorspar-lead-zinc potential of the property (Bending, 1978; Alonis, 1979). More recent work (Graf, 1981; personal communication, 1986) attempted to establish the economic potential of the property in terms of other commodities. It was during this latter work that the anomalous rare earth element (REE) content of claims was recognized.

GEOLOGY AND MINERALIZATION

The Rock Canyon Creek area is underlain by a Cambro-Ordovician to Middle Devonian carbonate-dominated sequence (Leech, 1979; Mott *et al.*, 1986). The regional stratigraphy has been previously described by Mott *et al.* (1986) and only relevant points will be reiterated here. The southwestern boundary of the property is marked by a west-dipping thrust fault which places Cambrian and Ordovician strata over younger rocks (*see* Figure 4-2-1). The remainder of the area is underlain by an overturned to upright homoclinal sequence, younging to the east. This succession comprises coral-rich limestones of the Ordovician Beaverfoot Formation in the northwest, unconformably overlain by buff-weathering dolomites and gypsum solution breccias of the basal Devonian unit which are, in turn, conformably overlain by fossiliferous and nodular grey limestones of the Fairholm Group. The fluorspar and REE mineralization is stratabound, hosted mainly by the basal Devonian unit.

Four main types of fluorite mineralization can be identified in the field. The first and most widespread consists of disseminations and fine veinlets of dark purple fluorite in a dark brown to dark orange-brown-weathering dolomitic carbonate matrix. Fluorite content generally varies from 2 to greater than 10 per cent of the rock. Disseminated pyrite, bastnaesite (CeCO$_3$F), gorceixite [(Ba, Ca, Ce)Al$_3$ (PO$_4$)$_2$ (OH)$_5$·H$_2$O] and barite are common accessory minerals (Hora and Kwong, 1986). Neutron activation analyses of up to 2.3 per cent rare earth elements and 2.7 per cent barium have been reported (C. Graf, personal communication, 1986). Niobium, strontium and yttrium are also present in measurable amounts (Hora and Kwong, 1986). Contacts between mineralized and unmineralized dolomitic rocks are gradational. This type of mineralization defines a northwest-trending zone mappable for over a kilometre subparallel to strike (Figure 4-2-1).

The second type of mineralization consists of massive, fine-grained purple and white fluorite, which commonly comprises greater than 40 per cent of the rock, together with accessory barite and prosopite [CaAl$_2$ (F, OH)$_8$] (Hora and Kwong, 1986). The rare earth element and pyrite contents of these rocks are relatively low. Massive fluorite mineralization has not been found in place, but relatively abundant float occurs at the southeast end of the zone of Type 1 mineralization, near the north-flowing branch of Rock Canyon Creek (Figure 4-2-1).

Fine-grained purple fluorite disseminated in white gypsum and locally interbedded with buff-weathering dolomite constitutes the third type of mineralization. Fluorspar is present in concentrations from trace amounts to a few per cent. Minor rare earth element enrichment is also reported (C. Graf, personal communication, 1986). This type of mineralization is found randomly distributed throughout the basal Devonian unit.

The fourth type of fluorspar mineralization occurs in rocks tentatively assigned to the Devonian Fairholm Group and is found in one locality, at the 2135-metre elevation on the ridge east of the headwaters of Rock Canyon Creek (Figure 4-2-1). Massive purple fluorite forms the matrix of an intraformational conglomerate and constitutes greater than 20 per cent of the rock.

DISCUSSION

A carbonatite-related origin has been suggested for the Rock Canyon Creek fluorite/rare earth showing (C. Graf, personal communication, 1986; Hora and Kwong, 1986). This interpretation appears consistent with preliminary geochemical data, which in addition to high fluorine, REE and barium, show enrichment in niobium, strontium, yttrium and phosphorus (C. Graf, personal communication, 1986; Hora and Kwong, 1986). Chondrite normalized rare earth element abundance patterns fall within the field defined by other British Columbia carbonatites (Figure 4-2-2);

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

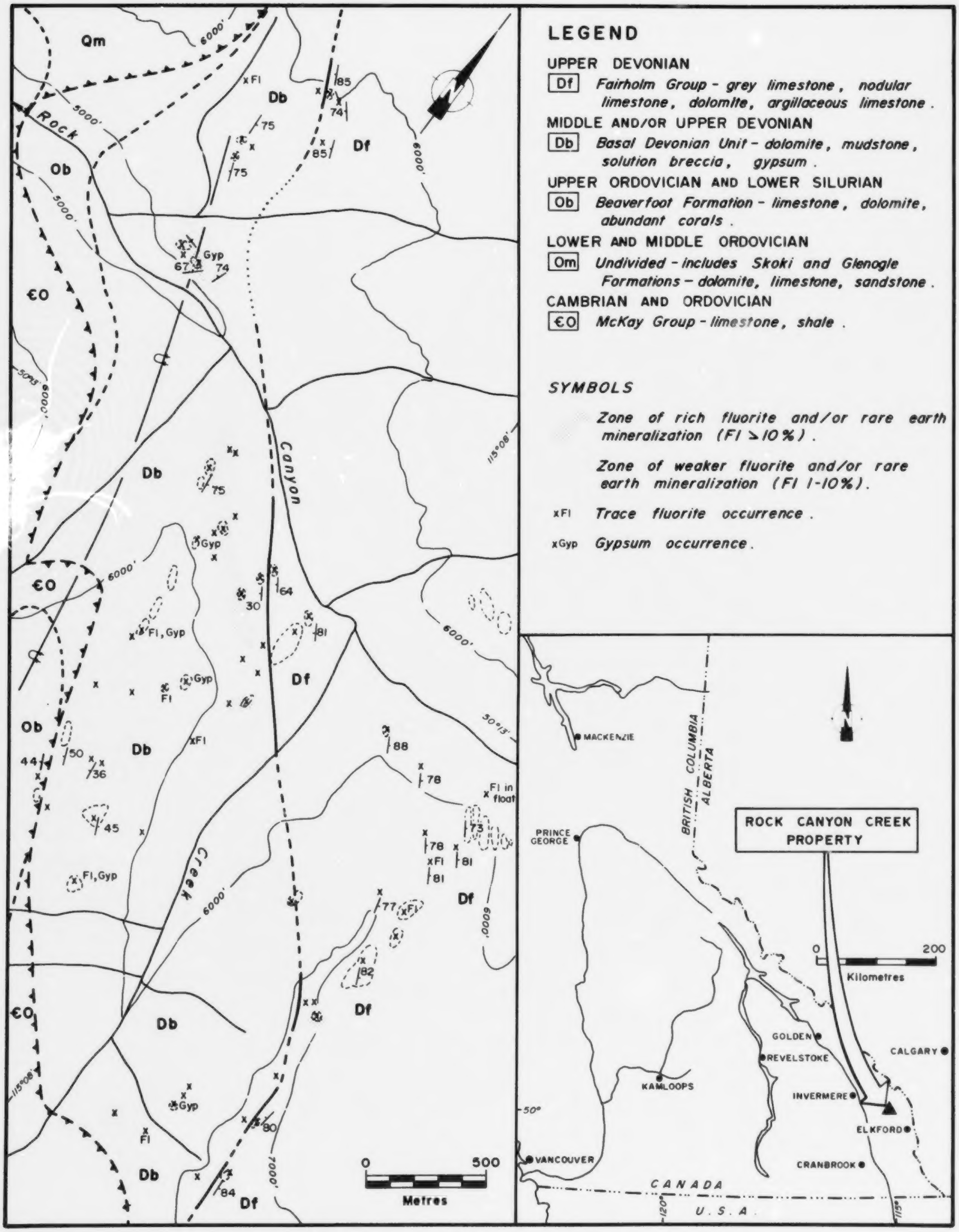
LEGEND
UPPER DEVONIAN
Df Fairholm Group - grey limestone, nodular limestone, dolomite, argillaceous limestone.
MIDDLE AND/OR UPPER DEVONIAN
Db Basal Devonian Unit - dolomite, mudstone, solution breccia, gypsum.
UPPER ORDOVICIAN AND LOWER SILURIAN
Ob Beaverfoot Formation - limestone, dolomite, abundant corals.
LOWER AND MIDDLE ORDOVICIAN
Om Undivided - includes Skoki and Glenogle Formations - dolomite, limestone, sandstone.
CAMBRIAN AND ORDOVICIAN
€O McKay Group - limestone, shale.
SYMBOLS
Zone of rich fluorite and/or rare earth mineralization (Fl ≥ 10%).
Zone of weaker fluorite and/or rare earth mineralization (Fl 1-10%).
xFl Trace fluorite occurrence.
xGyp Gypsum occurrence.
Rock
Canyon
Creek
Qm
Db
Df
Ob
€O
Gyp
Fl, Gyp
Fl in float
6000'
5000'
7000'
115°08'
50°13'
0
500
Metres
MACKENZIE
PRINCE GEORGE
KAMLOOPS
VANCOUVER
GOLDEN
REVELSTOKE
INVERMERE
ELKFORD
CRANBROOK
CALGARY
BRITISH COLUMBIA
ALBERTA
ROCK CANYON CREEK PROPERTY
0
200
Kilometres
CANADA
U.S.A.
50°
120°
115°

Figure 4-2-1. Geology of the Rock Canyon Creek fluorite/rare earth showing.

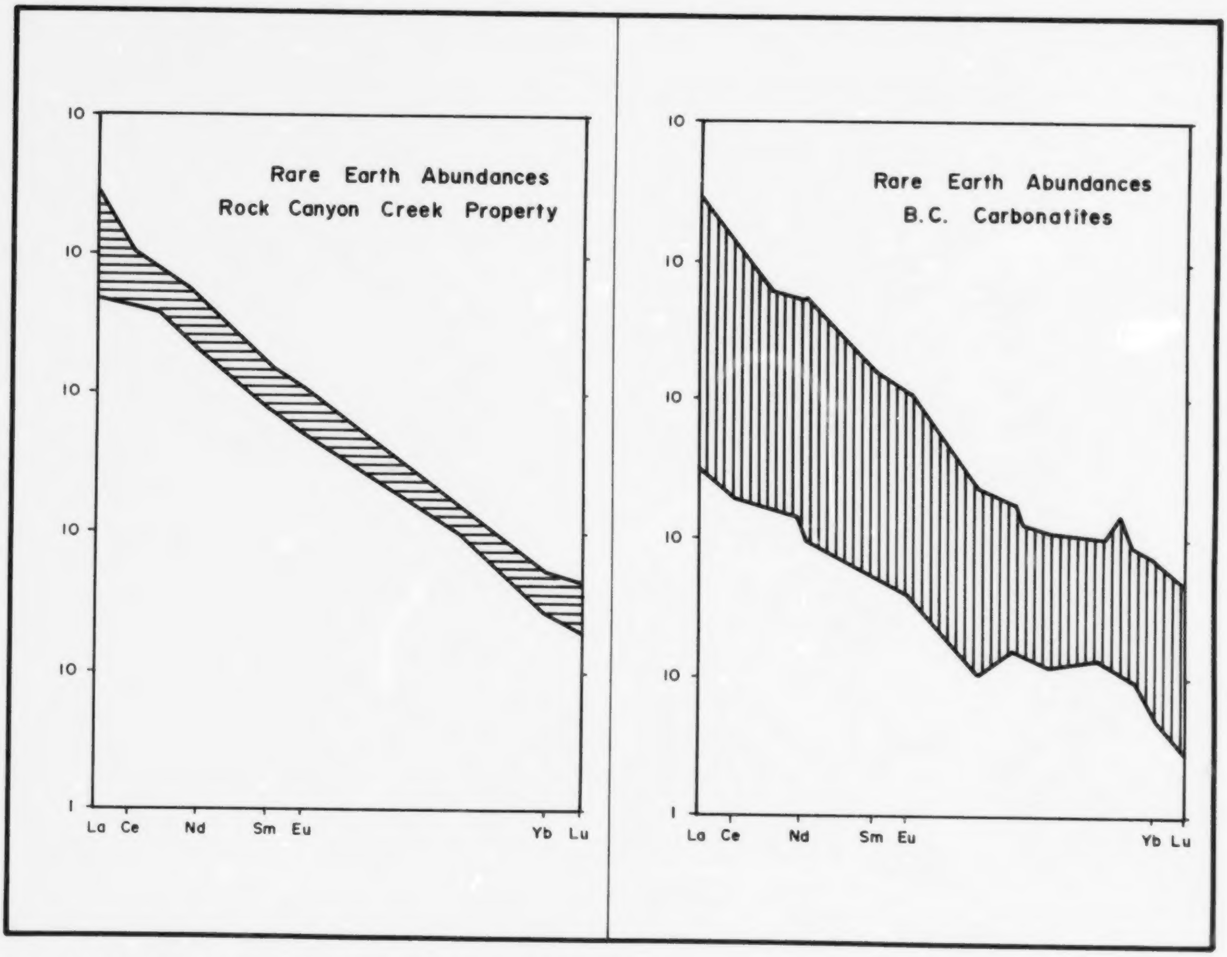

Figure 4-2-2. (A) Chondrite normalized REE plot of samples of Type 1 fluorite/rare earth element mineralization. Rare earth values from C. Graf (personal communication, 1986); chondrite normalizing factors from Henderson (1984, page 10). (B) Field of chondrite-normalized REE values for British Columbia carbonatites. Data from Pell (1986a; in preparation) and Höy and Pell (1986).

however the Rock Canyon Creek showing is more enriched in rare earths than most other examples, comparable only with the REE sweats and dykes associated with the Aley Complex (Pell, 1986a; Mäder, this volume).

Although a carbonatite-related origin appears to be the most reasonable interpretation, the timing and actual mode of formation have yet to be established. Two possibilities exist for the mode of formation of the main Type 1 mineralized zone: (1) carbonatite dykes or (2) metasomatically altered (fenitized) Devonian carbonate rocks, possibly associated with a deep-seated carbonatite intrusion. The latter interpretation is preferred due to the lack of unequivocal igneous material and the gradational contacts with fresh carbonates. Timing of metasomatism (or carbonatite intrusion) is also poorly defined. Mineralization apparently occurred prior to the Jura-Cretaceous deformation, as no fluorite is observed west of the west boundary fault, and postdated at least part of the deposition of the basal Devonian unit. This broadly defines a time span of 280 million years during which mineralization must have occurred. Some mineralization (Types 3 and 4, fluorite associated with solution breccias and intraformational conglomerate matrix) may have resulted from elemental remobilization, and therefore postdate the Type 1 and 2 fluorite/rare earth deposits. It has been suggested that mineralization may have been synchronous with deposition of the basal Devonian unit (C. Graf, personal communication, 1986). A slightly younger age seems probable as most other carbonatites in the province are Devono-Mississippian to Early Mississippian (*circa* 350 million years) in age (Pell, 1986b). Additional research is currently in progress to help resolve some of these ambiguities.

ACKNOWLEDGMENTS

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ALKALIC ULTRABASIC DIATREMES IN BRITISH COLUMBIA: PETROLOGY, GEOCHRONOLOGY AND TECTONIC SIGNIFICANCE*

(82G, J, N; 83C; 94B)

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INTRODUCTION

Alkalic ultrabasic diatreme breccias and dykes are known to occur in the Western and Main Ranges of the Rocky Mountains in three areas of British Columbia (Figure 4-3-1). With one exception (the Cross diatreme), all are hosted by Upper Cambrian to Ordovician/Silurian miogeoclinal rocks (Figures 4-3-2 and 4-3-3). The Cross diatreme, located in a more easterly structural position, is hosted by carbonate rocks of the Pennsylvanian/Permian Rocky Mountain Group (Figure 4-3-2). All the diatremes intruded the sedimentary sequence along the western margin of the North American continent, prior to the Jura-Cretaceous Columbian Orogeny and have been deformed, weakly metamorphosed and transported eastwards during orogenesis.

These diatremes have been targets for diamond exploration since the mid-1970s (Grieve, 1981; 1982; Dummet *et al.*, 1985; Pell, 1986a) even though most are not true kimberlites. The Cross diatreme (Hall *et al.*, 1986; Ijewliw, this volume) is unique among these intrusions as it is the only true kimberlite known in British Columbia (Grieve, 1981, 1982; Pell, 1986b). The other ultrabasic diatremes in the province, which fall into two groups based on lithologic similarities, age relationships and geographic location, will be dealt with in this paper.

THE BULL RIVER-ELK RIVER AREA (82G and 82J)

Forty or more breccia pipes and related dyke rocks occur within the Bull, White and Palliser River drainages east of the towns of Cranbrook and Invermere (Grieve, 1981). The majority of these are hosted by the Ordovician/Silurian Beaverfoot Formation and underlying Mount Wilson and/or Skoki Formations, and exhibit similarities in petrography, degree of alteration and morphology. In the southern part of the area, near Summer Lake (Figure 4-3-2) two small diatremes intrude the Upper Cambrian to Ordovician McKay Group (*see also* Grieve, 1981; Pell, 1986b). These two pipes are notably different from the others in the area, as will be discussed later.

THE RUSSELL PEAK DIATREMES (82J/6)

Diatremes in southern British Columbia are typified by those in the Russell Peak vicinity (Figure 4-3-2). One pipe, south of Russell Peak (grid reference 625950E, 5587000N), is particularly well exposed on a cliff face and displays many features of pipe morphology (Figure 4-3-4). The lower portion of the exposed pipe is comparable to the diatreme facies of a model kimberlite pipe (Clement and Reid, 1986). It comprises well-foliated, tuffisitic diatreme breccia containing abundant subangular sedimentary rock fragments and subrounded cognate xenoliths (autoliths) in a matrix of vesicular altered glass lapilli, carbonate, monocrystalline quartz xenocrysts and minor oxides. Exotic material is rare, if present. Rock fragments up to 25 centimetres in size are present, but the population mode is 2 centimetres and the clast:matrix ratio is approximately 1:1. The tuffisitic breccia is medium green in colour except along the pipe walls where it is red, due to the presence of abundant hematite. At the western margin of the pipe, near the base of the exposure, a coarse contact breccia crops out (Figure 4-3-4). It contains large (up to 4 or 5 metres), chaotic, angular wallrock fragments and subordinate matrix.

Between 50 and 100 metres of well-bedded pyroclastic and/or epiclastic material is exposed overlying the tuffisitic breccia (Figure 4-3-4; Plate 4-3-1A). At the base of this zone, the material is similar in composition to the tuffisitic breccia, with increasing amounts of sedimentary material upsection (crater zone, model pipe, Clement and Reid, 1986). Thin layers of igneous material are interbedded with the Ordovician-Silurian Beaverfoot Formation carbonate rocks near the top and margins of the exposed pipe, implying an Ordovician-Silurian age (*circa* 435-440 million years) for emplacement. The succession is unconformably overlain by Middle and/or Upper Devonian strata.

A small mafic body (flow?) is located near the exposed top of the crater zone (Figure 4-3-4) and represents the only unaltered material present in the diatreme complex. It is extremely porphyritic and comprises clinopyroxene and olivine phenocrysts, clinopyroxene microphenocrysts, oxides and plagioclase microphenocrysts in a fine-grained groundmass (cpx >> 01 ≥ oxides > plagioclase ≃ groundmass). Traces of potassium feldspar are also present. Ferromagnesian components comprise approximately 70 per cent of the rock. In a nearby diatreme, similar material occurs as small dykes crosscutting diatreme zone tuffisitic breccia, suggesting that this phase was emplaced late in the intrusive sequence.

The Russell Peak diatreme is morphologically similar to a model kimberlite pipe (Clement and Reid, 1986; Dawson, 1980; Hawthorne, 1975), but petrologically dissimilar. Additional work is necessary to allow classification.

Numerous other diatreme facies pipes are located in the Bull, White and Palliser River drainages. All are petrologically similar to the Russell Peak diatreme, all hosted by Ordovician-Silurian Beaverfoot Formation strata, and some also contain epiclastic and pyroclastic crater facies deposits (for example, Joff pipe, Shatch Mountain area, 82G/11; Pell, 1986b). Vesicular glass lapilli (Plate 4-3-1B) and a carbonate-rich matrix are ubiquitous. Some additional features, not observed at Russell Peak, are evident in the other diatremes and will be briefly outlined.

Diatremes west of the headwaters of Quinn Creek (82G/14, grid reference 619050E, 5526800N) are reported to contain macrocrysts of olivine and spinel up to 5 millimetres in size (Grieve, 1981) and rare granitic and altered ultramafic xenoliths. This diatreme also contains fossil fragments "floating" in tuffisitic breccia (Plate 4-3-1C). The richest xenolith population occurs in the Blackfoot diatreme, located on the ridge east of Blackfoot Creek (82G/14, grid reference 623350E, 5537200N; Pell, 1986b). Abundant pyroxenite and some dunite nodules are present, as well as rare spinel

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

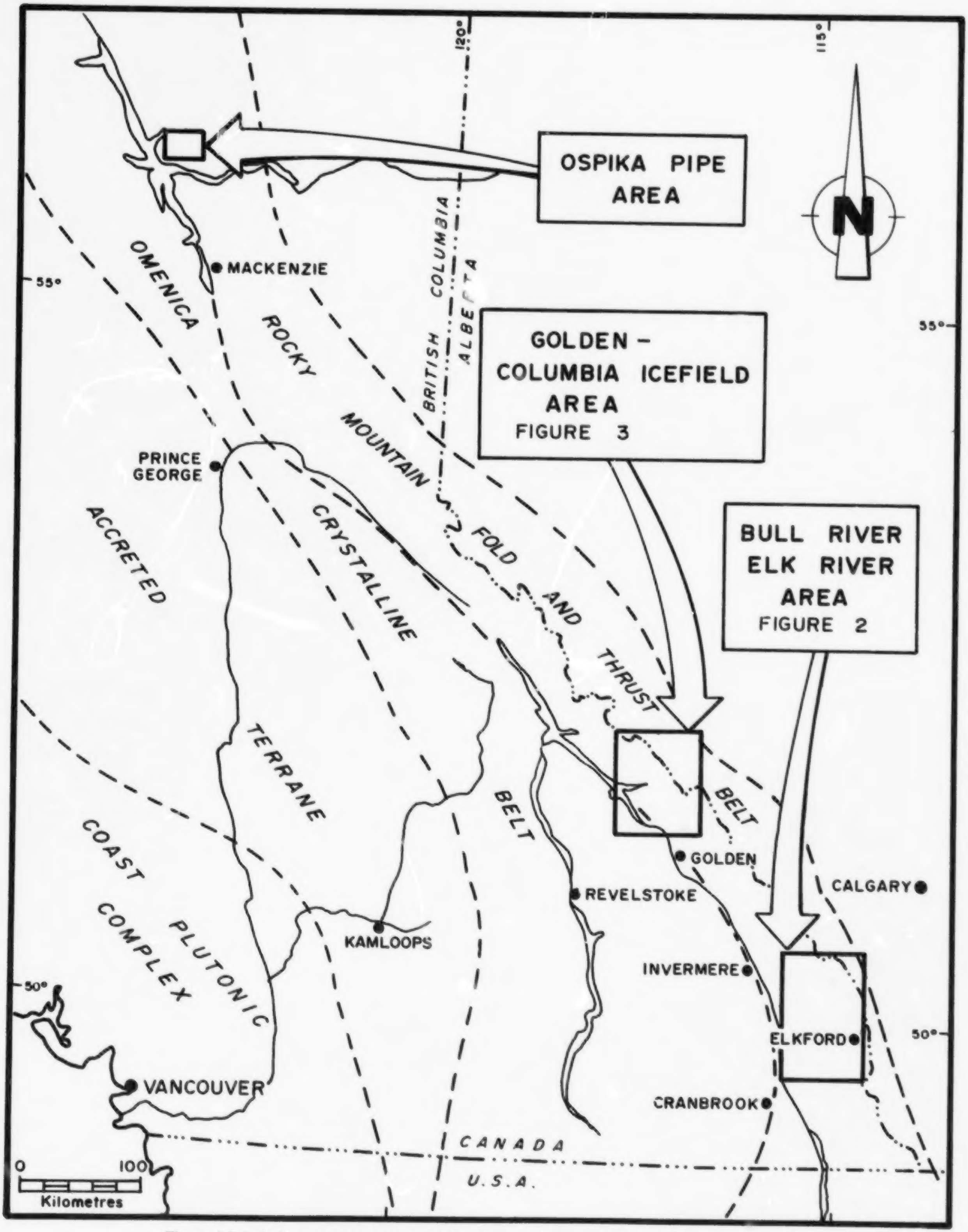
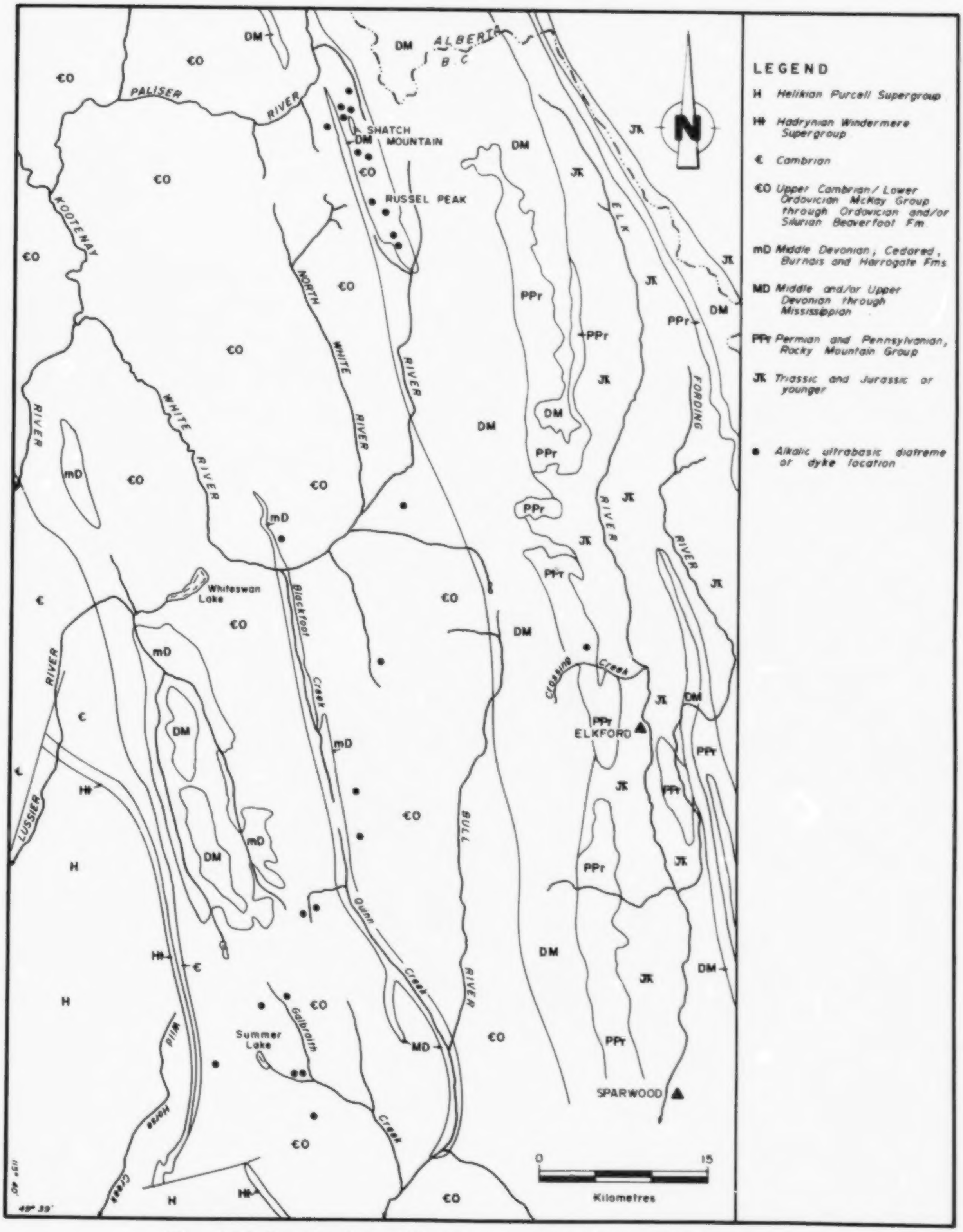

120°
115°
OSPIKA PIPE AREA
N
55°
55°
MACKENZIE
OMENICA
ROCKY
MOUNTAIN
FOLD
AND
THRUST
BELT
BRITISH COLUMBIA
ALBERTA
GOLDEN - COLUMBIA ICEFIELD AREA FIGURE 3
PRINCE GEORGE
ACCRETED
CRYSTALLINE
TERRANE
BELT
BULL RIVER ELK RIVER AREA FIGURE 2
COAST
PLUTONIC
COMPLEX
GOLDEN
REVELSTOKE
CALGARY
KAMLOOPS
INVERMERE
50°
50°
ELKFORD
VANCOUVER
CRANBROOK
CANADA
U.S.A.
0
100
Kilometres

Figure 4-3-1. Index map showing general locations of alkaline ultrabasic diatreme swarms. For detail on Ospika pipe, *see* Mäder (this volume).



ALBERTA
B.C.
PALISER RIVER
KOOTENAY
SHATCH MOUNTAIN
RUSSEL PEAK
NORTH WHITE RIVER
WHITE RIVER
RIVER
ELK RIVER
FORDING RIVER
Whiteswan Lake
Blackfoot Creek
Crossing Creek
ELKFORD
LUSSIER RIVER
BULL RIVER
Quinn Creek
Galbraith Creek
Summer Lake
Horse Creek
Wild Horse
SPARWOOD
N
0
15
Kilometres
115° 40'
49° 39'
H
Ħ
€
€O
mD
MD
DM
PPr
JR
LEGEND
H Helikian Purcell Supergroup
Ħ Hadrynian Windermere Supergroup
€ Cambrian
€O Upper Cambrian / Lower Ordovician McKay Group through Ordovician and/or Silurian Beaverfoot Fm
mD Middle Devonian, Cedared, Burnais and Harrogate Fms
MD Middle and/or Upper Devonian through Mississippian
PPr Permian and Pennsylvanian, Rocky Mountain Group
JR Triassic and Jurassic or younger
● Alkalic ultrabasic diatreme or dyke location

Figure 4-3-2. General geology and diatreme locations in the Bull River/White River area. Geology modified from Leech (1960, 1979).

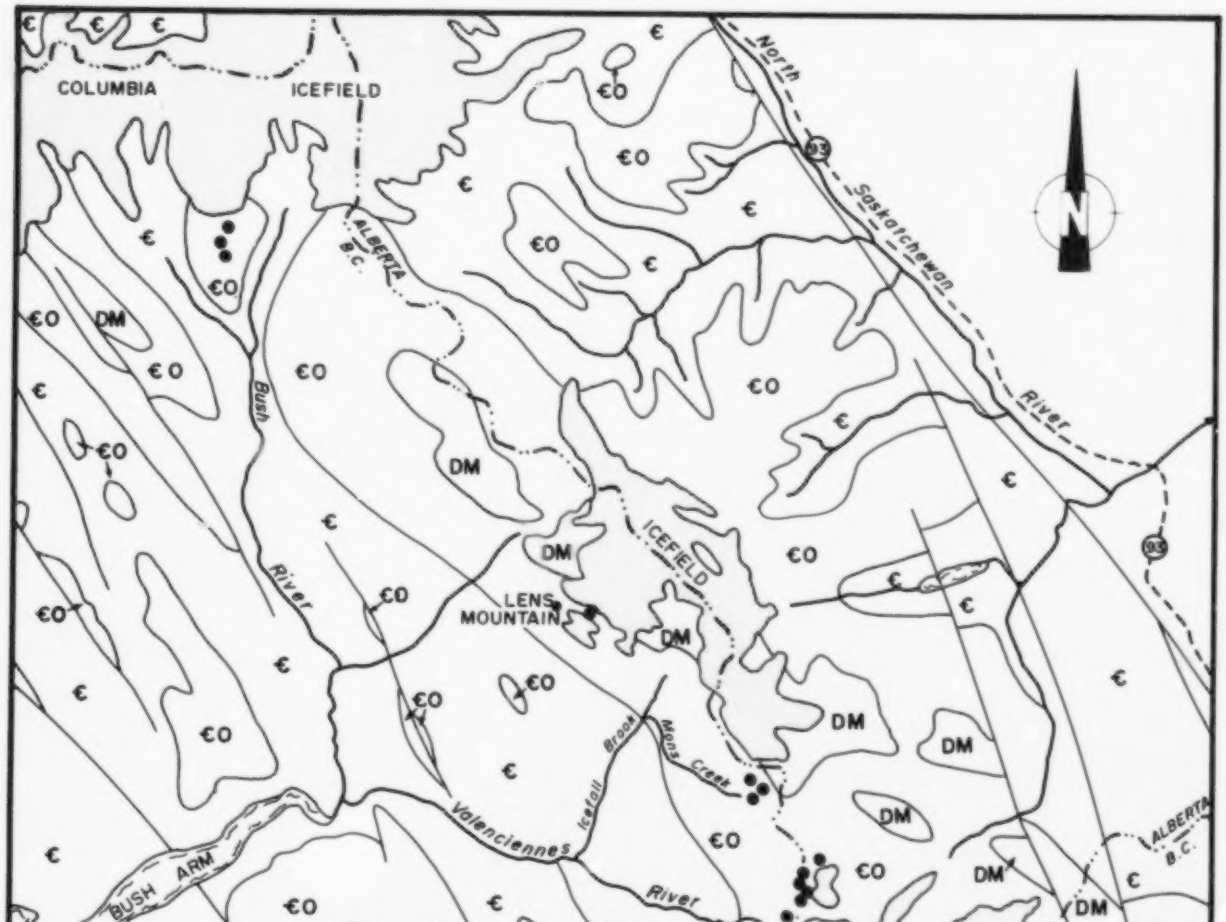

COLUMBIA
ICEFIELD
ALBERTA
B.C.
North
Saskatchewan
River
93
Bush
River
LENS MOUNTAIN
ICEFIELD
Icefall
Brook
Mons Creek
Valenciennes
River
BUSH ARM
FRESHFIELD
ICEFIELD
CAMPBELL ICEFIELD
COLUMBIA
REACH
Waitabit
Creek
Blaeberry
River
€
€O
DM
N
0
10
Kilometres

Figure 4-3-3. General geology and diatreme locations in the Golden-Columbia Icefield area. Geology modified from Wheeler (1962) and Price (1967a, b). ● indicates diatremes or dykes. For legend, *see* Figure 4-3-2.

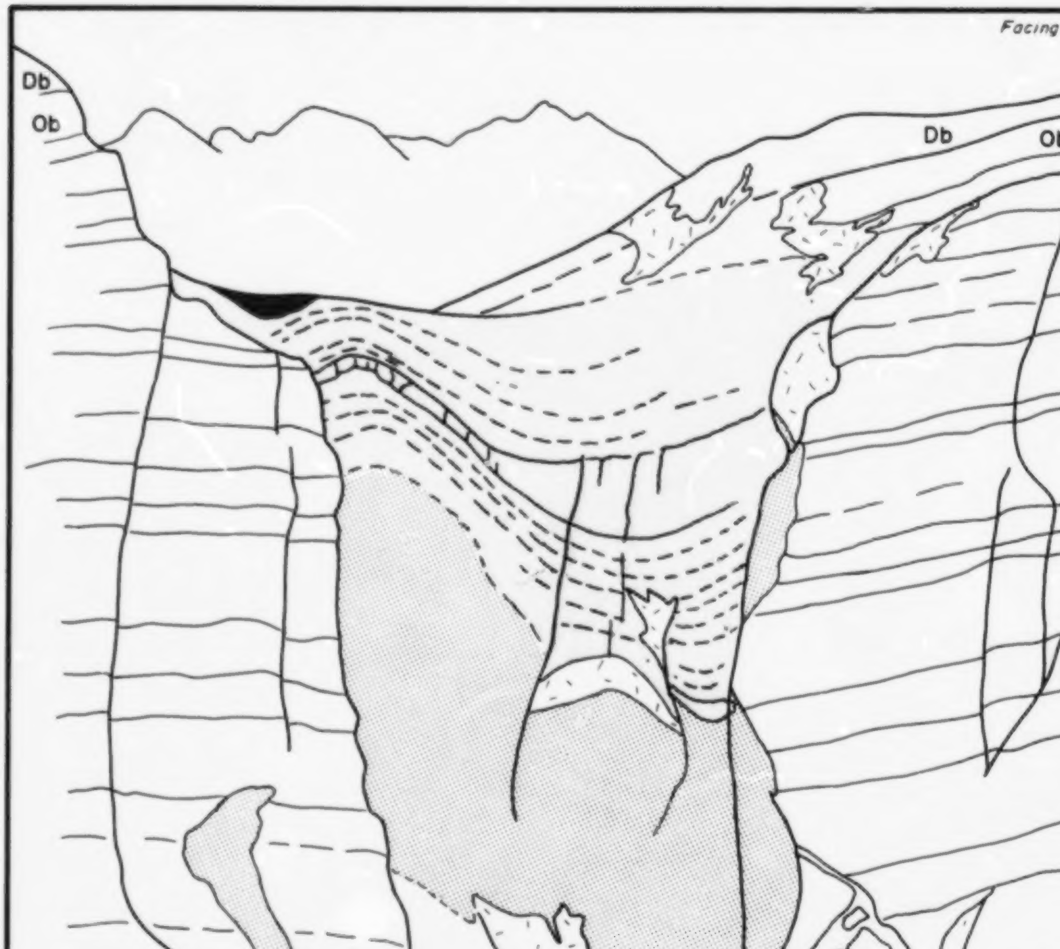

Facing South
Db
Ob
Db
Ob
Ob
Osk
Ob
Osk
Ob
Osk
talus slope
LEGEND
Coarse contact breccia.
Diatreme breccia material / tuffite.
Epiclastic and/or pyroclastic material mixed with sediment.
Mafic volcanic rock.
Snow patch.
Db Basal Devonian unit.
Ob Ordovician Beaverfoot Formation.
Osk Ordovician Skoki Formation.
0
50
Metres

Figure 4-3-4. Geology of the Russell Peak diatreme.

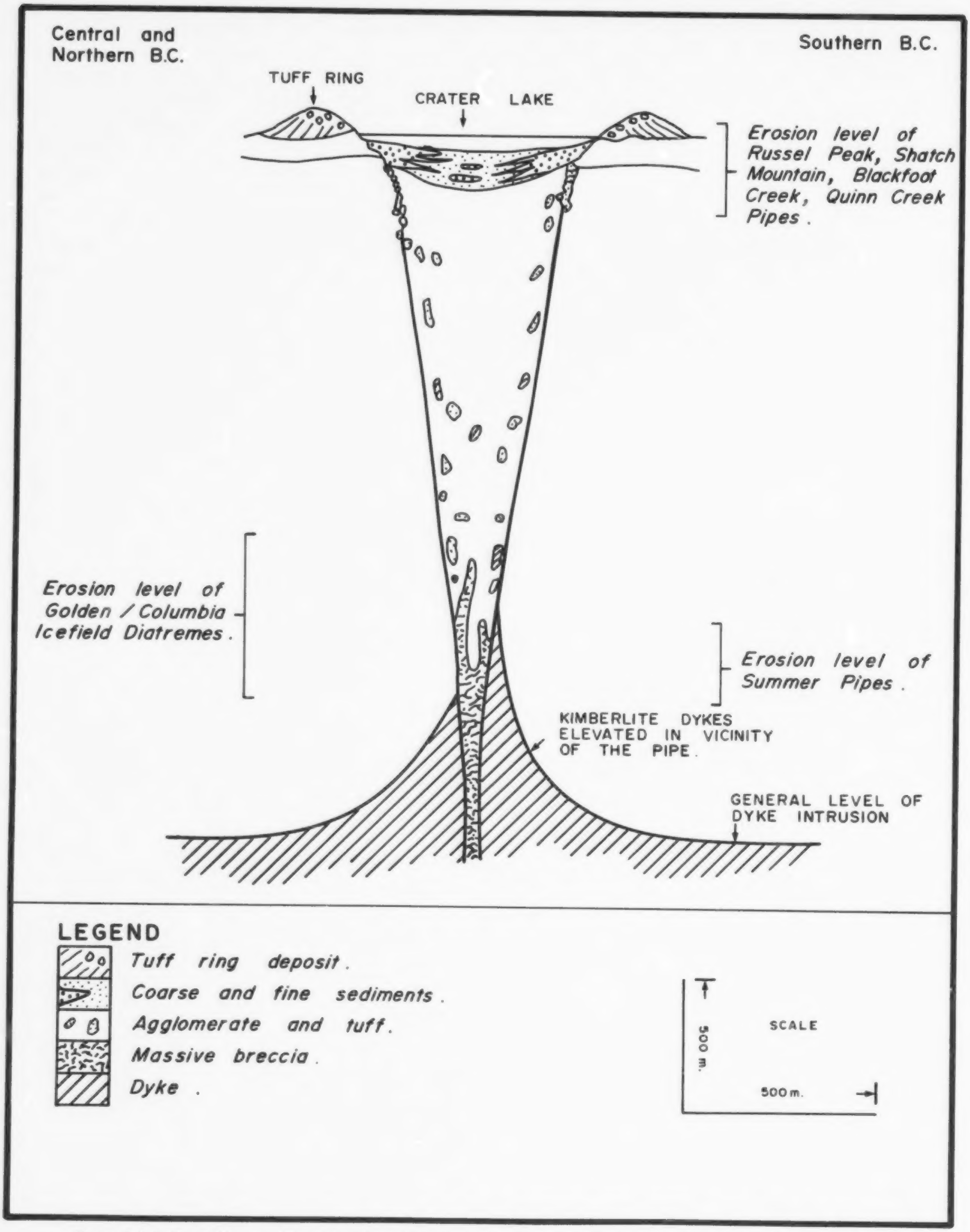

Central and Northern B.C.
Southern B.C.
TUFF RING
CRATER LAKE
Erosion level of Russel Peak, Shatch Mountain, Blackfoot Creek, Quinn Creek Pipes.
Erosion level of Golden / Columbia Icefield Diatremes.
Erosion level of Summer Pipes.
KIMBERLITE DYKES ELEVATED IN VICINITY OF THE PIPE.
GENERAL LEVEL OF DYKE INTRUSION
LEGEND
Tuff ring deposit.
Coarse and fine sediments.
Agglomerate and tuff.
Massive breccia.
Dyke.
500 m.
SCALE
500 m.

Figure 4-3-5. Generalized model of a South African kimberlite diatreme (from Dawson, 1980 and Hawthorne, 1975) with suggested erosion levels of British Columbia diatremes.

lherzolites (Ijewliw, 1986, this volume). Eclogite nodules have also been reported (Godwin, personal communication, 1985). Clinopyroxene, orthopyroxene and spinel macrocrysts are also present in the Blackfoot pipe.

SUMMER CREEK DIATREMES (82G/11)

Two small intrusive bodies are found at the intersection of Galbraith and Summer Creeks (Figure 4-3-2). They differ from those previously described in a number of ways: (1) they are hosted by Late Cambrian McKay Formation strata (Pell, 1986b), not by Ordovician-Silurian formations; (2) they are massive, brown-weathering, weakly foliated breccias as opposed to dominantly green-weathering, well-foliated tuffisitic breccias; (3) they are devoid of volcanic glass lapilli (Figure 4-3-10) and (4) fine-grained dykes, which may be associated with the diatreme, intrude surrounding sediments (Pell, 1986b) but do not cut the pipes themselves. The Summer pipes are further characterized by complex internal geology; several discrete breccia phases with variable clast composition and content and variable amounts of carbonate in the matrix are present. Contacts between breccia phases are generally gradational. The Summer Creek pipes represent a deeper erosional level than those elsewhere in the Bull, White and Palliser River areas, corresponding to the root zone (Clement and Reid, 1986; Dawson, 1980, Hawthorne, 1975) of a model kimberlite pipe (Figure 4-3-5).

GOLDEN-COLUMBIA ICEFIELDS AREA (82N/83C) AND THE OSPIKA RIVER AREA (94B)

Numerous diatremes are located along the Alberta-British Columbia border between 50 and 90 kilometres north of the town of Golden (Figure 4-3-3). Most are hosted by Upper Cambrian strata and in most cases, consanguineous dykes are also present. Characteristics of the pipes suggest that they represent deep erosional levels in a model pipe (root zone, Clement and Reid, 1986; *see* Figure 4-3-5).

Microdiamonds have reportedly been recovered from heavy mineral separates taken from two of the pipes in this swarm (Dummett *et al.*, 1985). Preliminary investigations suggest that these rocks are a suite different from those in the south, but still not true kimberlites. Further research currently in progress (M.Sc. thesis, O. Ijewliw, Queen's University) will detail the petrology and diamond potential of the Golden diatremes. One pipe has been reported from the Ospika River area. It is similar in many respects to the diatremes in the Golden area and will be briefly discussed with them.

THE HP PIPE (82N/10)

The HP pipe, located south of the Campbell Icefield (Figure 4-3-3), is the smallest, but best exposed and preserved of the diatremes in the area. Preliminary geology (Pell, 1986b) and petrology (Ijewliw, this volume) have been reported on, but a second visit, during the summer of 1986, has provided additional information. The HP pipe is a composite diatreme comprising five distinctly different breccia phases and at least that many petrologically differentiable dyke phases. The breccias differ in clast to matrix ratios, megacryst abundances (black augite, green diopside, phlogopite/biotite) and the presence or absence of additional phases such as garnets, oxides and accretionary lapilli or pellets (Plate 4-3-2A). Contacts between breccia phases may be gradational or sharp.

A rubidium-strontium age date of 348±7 million years has been obtained on mica separates from this pipe, suggesting a 100-million-year difference in age from the pipes in southern British Columbia.

VALENCIENNE RIVER PIPES (MARK CLAIMS, 82N/15)

Four or more diatremes and numerous dykes are hosted by Upper Cambrian rocks near the headwaters of Valencienne River (Figure 4-3-3). Two distinctly different types are present. The first are rusty brown-weathering, weakly to well-foliated composite pipes with both massive and breccia phases. Serpentinized olivine macrocrysts (Plate 4-3-2B), coarse nonmagnetic oxides and altered peridotite xenoliths are present in some phases. Typical breccias contain 40 per cent clasts, most of which are small (1 to 5 centimetres) subangular sedimentary rock fragments (Pell, 1986b). Associated dyke rocks are fine to medium grained, extremely altered and porphyritic. The phenocryst assemblage, as can be recognized, consists of olivine, pyroxene and mica. In some phases olivine appears more abundant than pyroxene (ol>px≥mica) and in others pyroxene is far more abundant (px>ol≥mica). Oxides are a common groundmass constituent. The dykes are generally peripheral to the diatremes, but locally crosscut them.

The second type of diatreme present is brown-weathering and moderately well foliated with angular to subangular sedimentary rock fragments set in a matrix of quartz grains, chlorite and carbonate. Clasts average 1 to 5 centimetres in size with some up to 20 centimetres. The clast:matrix ratio is 2:3. Although dominantly comprised of sedimentary material, these rocks are intrusive and may be formed through fluidizing of sediment by introduction of volatiles explosively exsolved from rising and vesiculating magmas.

MONS CREEK AND LENS MOUNTAIN AREAS (82N/14, 15)

At both Mons Creek and Lens Mountain (Figure 4-3-3) the dominant intrusive lithology consists of a buff-weathering, weakly foliated breccia with a low clast to matrix ratio (approximately 1:3). Clasts are small subangular sedimentary rock fragments, predominantly carbonates, in a matrix of quartz grains, carbonate and iron oxides. This material is similar to the second type of diatreme at Valencienne River, but has a higher percentage of matrix. At Mons Creek, a small light green, strongly foliated, fine-grained intrusive breccia (apparently igneous) also crops out. It contains fragments of less than 1 centimetre size and oxides in a carbonate and hematite matrix. One small, crosscutting dyke and abundant unaltered porphyritic dyke float were observed. The dyke material comprises primary phenocrystal titaniferous augite, biotite and chrome spinel with or without olivine (cpx>>bi>spinel). Similar dyke material was not observed at Lens Mountain.

BUSH RIVER AREA (83C/3)

Near the headwaters of Bush River (Figure 4-3-3) a suite of dykes and small diatremes, somewhat similar to those at Valencienne River, intrude Upper Cambrian strata. The diatremes are clast-dominated (clast:matrix ratio is approximately 3:2) containing subangular sedimentary material and subordinate rounded granitic, gabbroic and cognate xenoliths (autoliths). Accretionary lapilli (pellets) and mica megacrysts are important phases in one pipe. Dykes are of two main types, homogeneous and zoned. The zoned dykes have coarse xenolith and/or xenocryst-rich cores (Plate 4-3-2C) and fine-grained margins. Contacts within the dyke may be gradational or distinct and often the margins exhibit a banded texture (Plate 4-3-2D). Mica is an essential component; pyroxene, olivine and chrome spinel or other opaque oxides may also be present. Most dykes are extremely altered.

OSPIKA PIPE (94B/5)

The Ospika pipe (Pell, 1986b) is a small composite diatreme containing at least five distinct breccia and massive phases. Phlogopite dominates the macrocryst assemblage, with titaniferous augite, green diopside and olivine also locally present in a fine-grained carbonate-dominated matrix. Dykes of similar material are found over 1 kilometre away from the diatreme. Rubidium/strontium age dating of mica separates has yielded an age of 334 ± 7 million years for the Ospika pipe.

DISCUSSION AND CONCLUSIONS

Three petrologically, geographically, and temporally distinct suites of ultrabasic diatremes can be recognized in British Columbia. The first is found in the Bull River area (Figures 4-3-1 and 4-3-2). Examples of both deep erosional levels (that is, root zones) and surface expression (upper diatreme and crater zones) of pipes have been recognized. The upper reaches of the diatreme zone are characterized by an abundance of vesiculated glass lapilli. The crater zone contains bedded epiclastic and/or pyroclastic rocks. Toward the periphery of the crater thin layers of igneous material are interbedded with Ordovician/Silurian Beaverfoot carbonate rocks, suggesting an age of emplacement of approximately 435 to 440 million years. The root zones of these pipes comprise macrocryst-poor breccias; chrome spinels and possibly altered olivines are sporadically distributed throughout.

The second suite, examples of which are found north of Golden and in the Ospika River areas (Figures 4-3-1 and 4-3-3), is characterized by macrocryst-rich breccias and dykes. The macrocryst population consists of titaniferous augite, phlogopite, green diopside, spinel and olivine, with either augite or phlogopite most abundant. These pipes represent the deeply eroded root zones of diatremes. Rubidium-strontium age dates of 334 ± 7 and 348 ± 7 million years have been obtained on two of the pipes.

The third petrologically distinct rock type is represented by one example, the Cross kimberlite, located at Crossing Creek, north of the town of Elkford (Figure 4-3-2). As the name implies, it is the only true kimberlite so far recognized in the province. It also is apparently a deeply eroded pipe remnant and contains olivine, phlogopite, pyroxene, garnet and spinel megacrysts as well as peridotite and garnet and spinel lherzolite nodules (Hall *et al.*, 1986). Rubidium-strontium dating of mica separates has yielded ages of 240 and 244 million years (Grieve, 1982; Hall *et al.*, 1986) for the Cross kimberlite.

The age dating indicates three periods of emplacement for ultrabasic diatremes in the Canadian Cordillera. Intrusion appears to be related to extension and/or rifting along the western continental margin which both initiated, produced and deepened the basin into which the miogeoclinal succession was deposited. A major period of alkaline activity occurred *circa* 350 million years when carbonatites and alkalic syenites as well as the diatremes were emplaced (Pell, 1986c). Xenoliths in the pipes (granitics, marbles, etc.) indicate that the diatremes passed through continental crust and therefore the miogeoclinal rocks which host them rest on continental basement.

At this point it is difficult to completely assess the depth of origin and diamond potential of these rocks. When compared to current models (Haggerty, 1986) it appears that the probability of the British Columbia diatremes containing diamonds is low. From craton to margin, a sequence of kimberlite plus diamond, kimberlite without diamond (for example, Cross) and diamond-free ultrabasic diatremes (nonkimberlitic, for example, Russell Peak pipes) is commonly proposed (Haggerty, 1986). If this model is applicable to western North America, diamonds should not be found in British Columbia as most diatremes originated too far outboard of the continent. However, much more work is necessary before this hypothesis can be accepted or rejected.

ACKNOWLEDGMENTS

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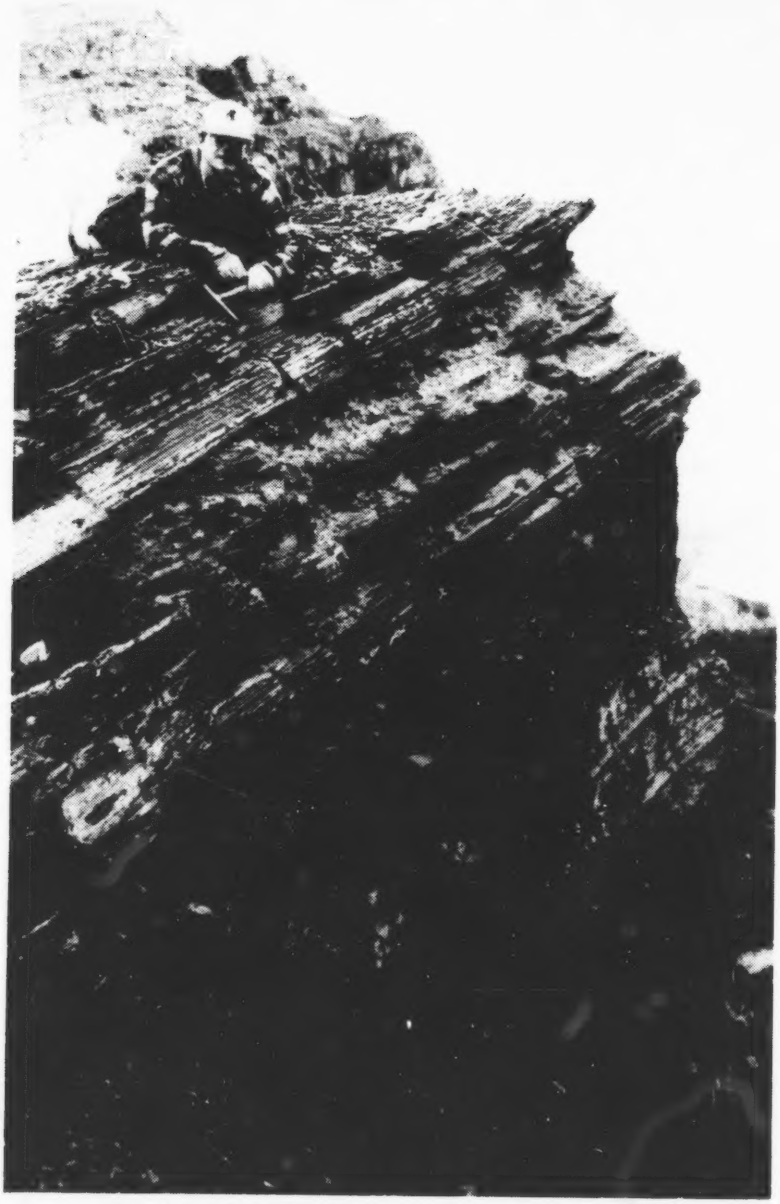
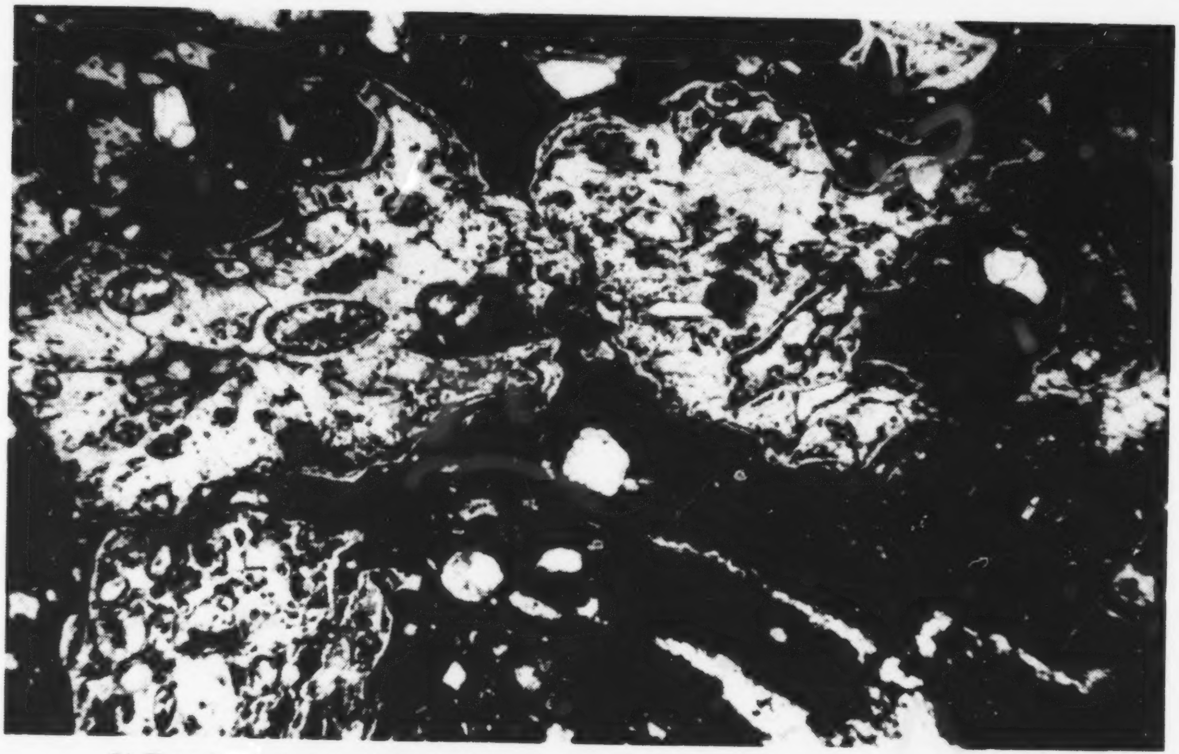
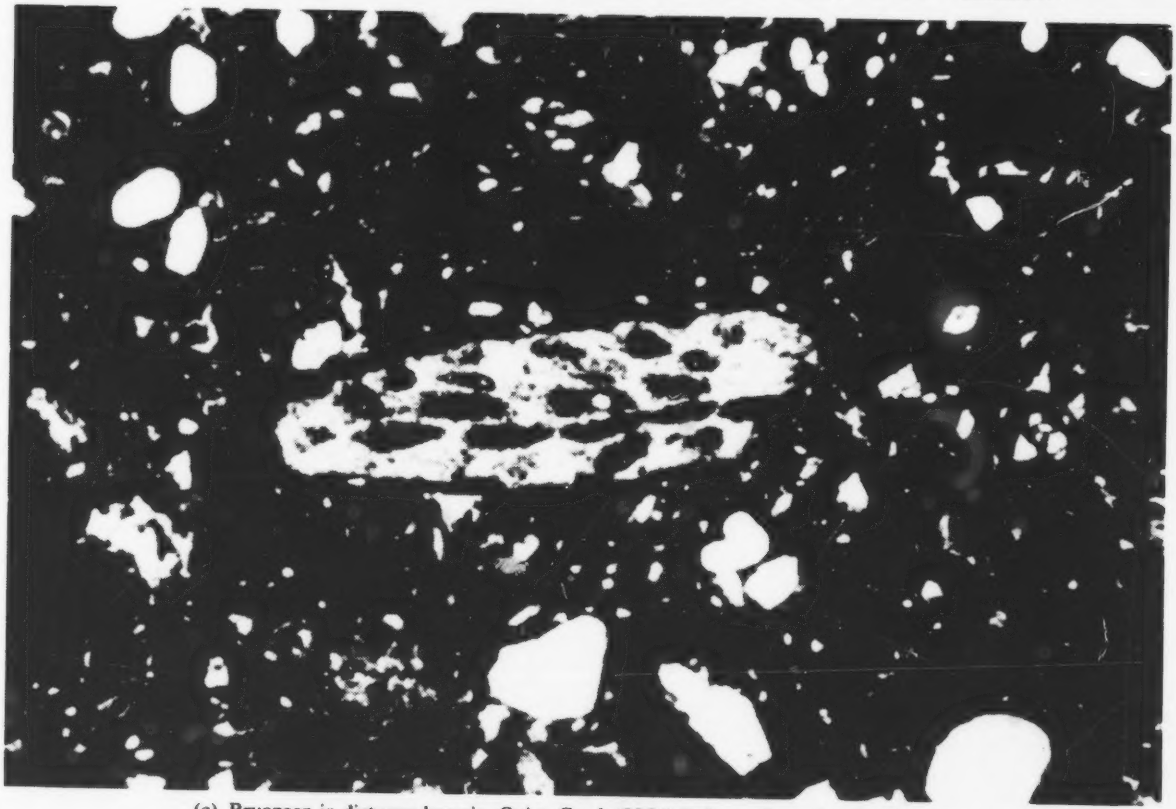


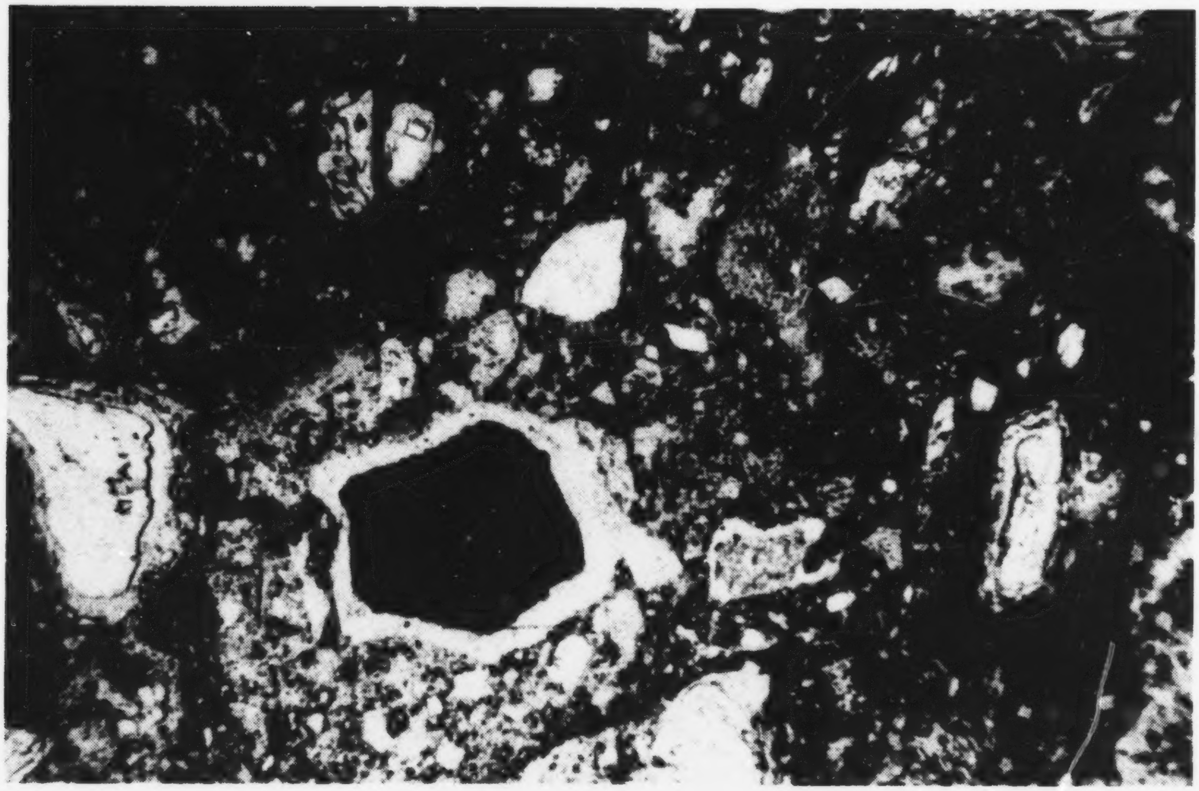
Plate 4-3-1. Characteristics of diatremes in the Bull River area.
(a) Bedded epiclastic crater infill material, Russell Peak area (82J/6). Note the resistant sedimentary layers.



(b) Photomicrograph of a vesicular glass lapilli, Quinn Creek pipe (82G/14). Long dimension 7 millimetres.



(c) Bryozoan in diatreme breccia, Quinn Creek (82G/14). Long dimension 7 millimetres.



(d) Typical material from Summer pipe (82G/11). Note chrome spinel (dark grain near centre of view) and lack of glass lapilli. Long dimension 7 millimetres.

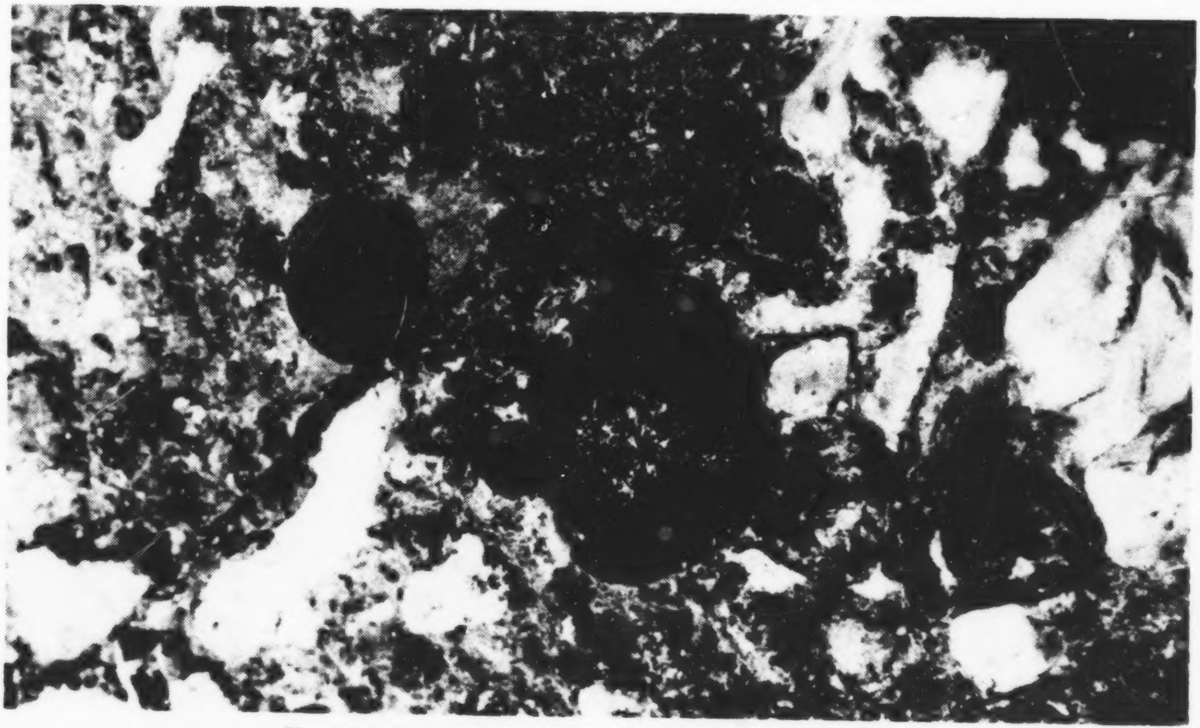
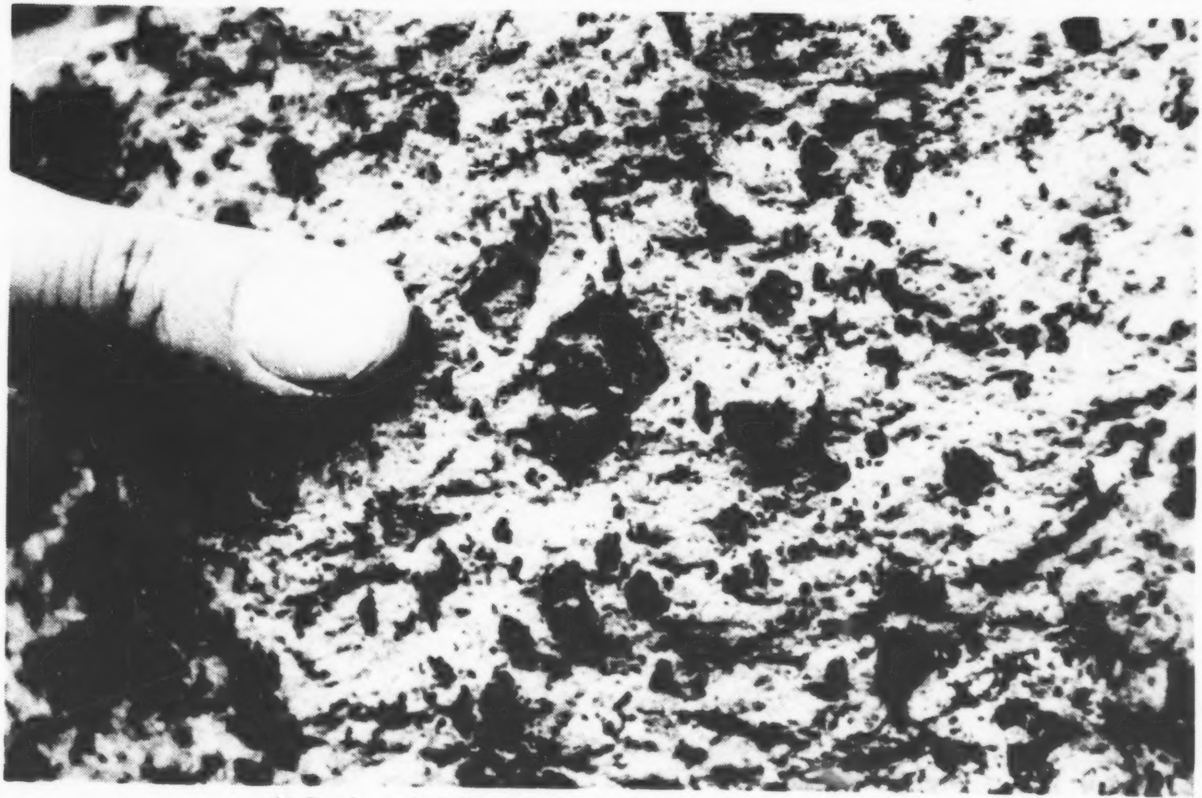
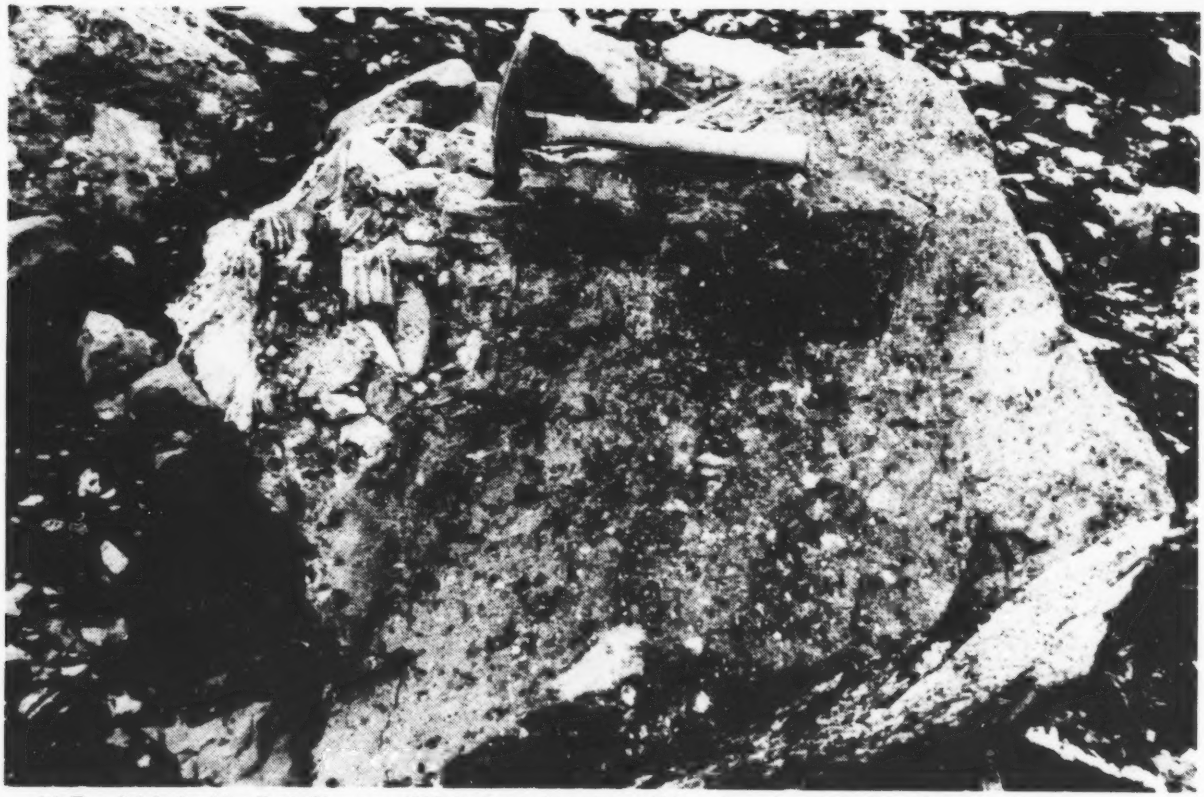


Plate 4-3-2. Characteristics of the Golden diatremes and related rocks.

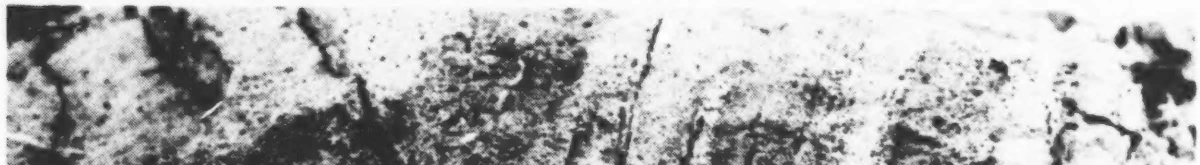
(a) Accretionary lapilli, HP pipe (82N/10). Note pyroxene megacryst forming core of lapilli.



(b) Pseudomorphed olivine macrocrysts, Valencienne River area (82N/15).



(c) Zoned dyke boulder, Bush River area (83C/3). Coarse breccia would have formed core of dyke, with finer-grained margins.



(d) Finer grained dyke, Bush River area (83C/3). Note layering parallel to the margin of the dyke.

COMPARATIVE MINERALOGY OF THREE ULTRAMAFIC BRECCIA DIATREMES IN SOUTHEASTERN BRITISH COLUMBIA CROSS, BLACKFOOT AND HP*

(82J, 82G, 82N)

By Olga J. Ijewliw
The University of British Columbia**

INTRODUCTION

A series of ultramafic breccia diatremes occurs along a northwest trend line east of the Rocky Mountain Trench in British Columbia (Figure 4-4-1). Three of these, Cross, Blackfoot and HP diatremes, were selected for comparative study. All three were intruded into Paleozoic miogeoclinal sediments prior to deformation associated with the Columbia Orogeny (Pell, 1986) and have been considered to have kimberlitic affinity (Dummett *et al.*, 1985; Grieve, 1981 and 1982).

The purpose of this study is to classify the diatremes where possible, and to compare and contrast their petrography, mineralogy and chemistry.

THE CROSS DIATREME (82J/2)

INTRODUCTION

The Cross diatreme lies north of Crossing Creek about 10 kilometres northwest of the village of Elkford at latitude 50°05'25"N, longitude 114°59'30"W. Access is by helicopter or by four-wheel-drive vehicle and a three-hour hike. The outcrop is a steep bluff some 15 metres high and 50 to 60 metres long. The slope below is covered with natural diatreme talus and material derived from road construction.

DESCRIPTION

The diatreme is lithologically heterogenous and very friable. The west end of the outcrop is a light green, strongly foliated rock containing some red hematized clasts. Foliation is at a high angle to bedding in adjacent sediments. This grades eastwards to a massive, light green unit with 40 per cent inclusions including 5 to 10 per cent ultramafic xenoliths. Further east the rock is a dark green, massive, unfoliated unit with fewer clasts but containing abundant, randomly distributed phlogopite books and ultramafic xenoliths. Bright red hematization is progressively more evident toward the top and centre of the outcrop where entire mineral or xenolithic fragments may be hematized. Pyrite is present as discrete grains in the groundmass and as rims surrounding clasts where it may, in turn be enveloped by ragged, bright red hematite.

The several distinct lithologies may reflect separate intrusive pulses. A shear zone cuts the diatreme vertically with the eastern third being downdropped slightly.

Inclusions comprise 15 to 20 per cent of the rock volume and consist of angular fragments of country rock, rounded, dark green serpentinized xenoliths and black pyroxenite xenoliths. The rounded xenoliths range in size from a few millimetres to 6 centimetres in diameter.

DETAILED PETROGRAPHY

Xenoliths are almost entirely serpentinized pseudomorphs of olivine and pyroxene (Plate 4-4-1). Serpentine is markedly finer grained at the xenolith margins. Talc replaces pyroxene to a limited extent and also rims and veins serpentinized grains. The original presence of olivine is indicated by the typical olivine outline and fracture pattern. Olivines are completely serpentinized. Some relict pyroxene with characteristic cleavage and birefringence is preserved. The degree of alteration in the pyroxenes often makes the identification difficult. Interstitial spinels are also present in minor amounts. The xenoliths may therefore be broadly classified as spinel lherzolites.

The interstitial spinels analysed on the energy dispersive system of the scanning electron microscope are in the chromite-hercynite solid solution series and can best be represented by the formula $(Fe,Mg)(Cr,Al)_2O_4$.

Macrocrysts (0.5-5.0 millimetres) consist of completely serpentinized olivines (Plate 4-4-2), partially altered garnets, garnets with kelyphitic rims (Plate 4-4-3) and phlogopites (Plate 4-4-2). They may be round, oval or lath-shaped in random orientation and make up 10 to 20 per cent of the rock volume. Garnets show a moderate to high degree of alteration or dissolution in reaction with the matrix. None are euhedral. They are rounded and irregular in shape and surrounded by kelyphitic rims or reaction coronas of opaque iron oxides (Plate 4-4-3). Fracturing is common, with serpentine forming in the fractures. Occasionally, calcite rimmed with phlogopite and sitting in serpentine, is nested in a garnet. In plane polarized light, the garnets exhibit a range of colours from clear to light pinkish brown and pale green. X-ray spectra of clear and brown garnets show roughly similar compositions in the pyrope-almandine-grossular range with minor amounts of titanium and chromium.

Phlogopites are occasionally zoned. Many grains are bent and show undulating extinction. Occasionally grains are intergrown. Alteration, which is relatively rare, occurs as embayments, pockets and central sieving. X-ray spectra confirm that the micas are phlogopite and contain appreciable amounts of titanium.

Xenocrystic quartz grains, singly and in aggregates, occur in the eastern part of the diatreme, probably representing mixing with the intruded sedimentary rocks.

The phenocryst population is comprised of completely serpentinized olivine, together with phlogopite and spinel. Phlogopite grains vary in size and are randomly oriented, square to rectangular in shape and relatively unaltered (Plate 4-4-2). Zoning is rare but grains may be intergrown. Reddish brown translucent spinels are disseminated in the groundmass and show magnetite reaction rims. Spinels may also be surrounded by phlogopite.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

** Presently at Queen's University, Kingston, Ontario.

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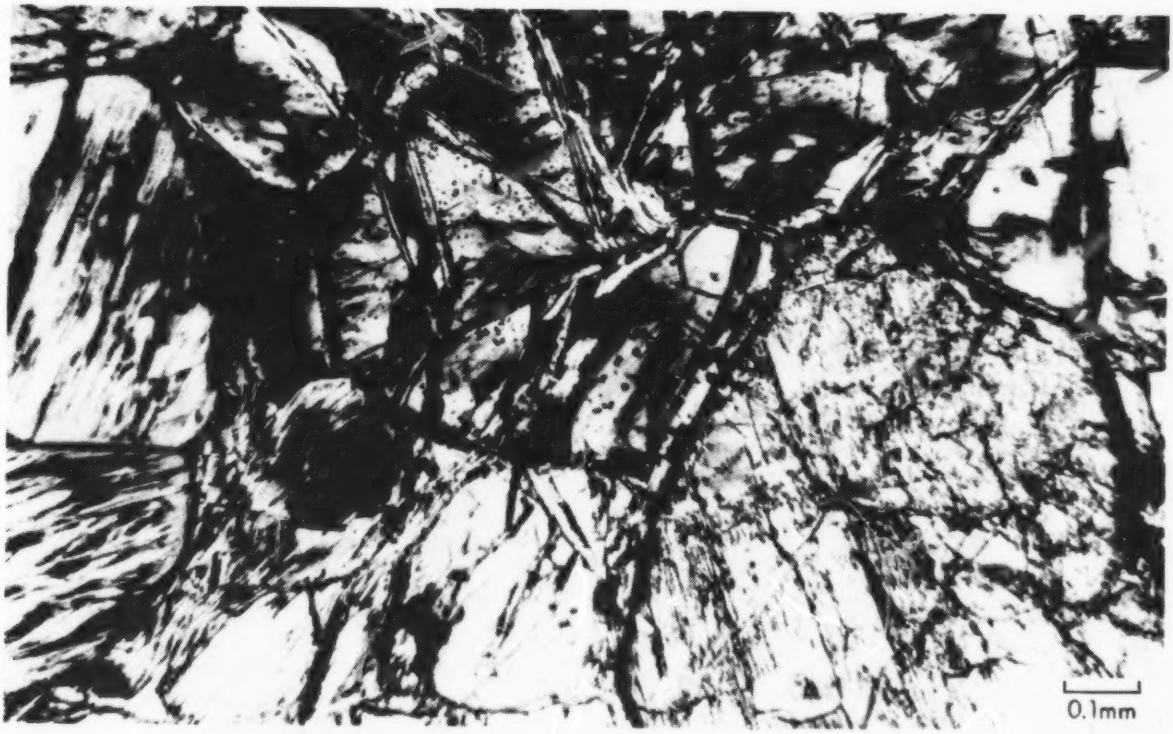

Plate 4-4-1. Cross diatreme xenolith showing serpentinized olivine with characteristic fracture pattern (top half) and serpentinized pyroxene with relict cleavage and birefringence (bottom half); field of view = 1.80 millimetres. XPL

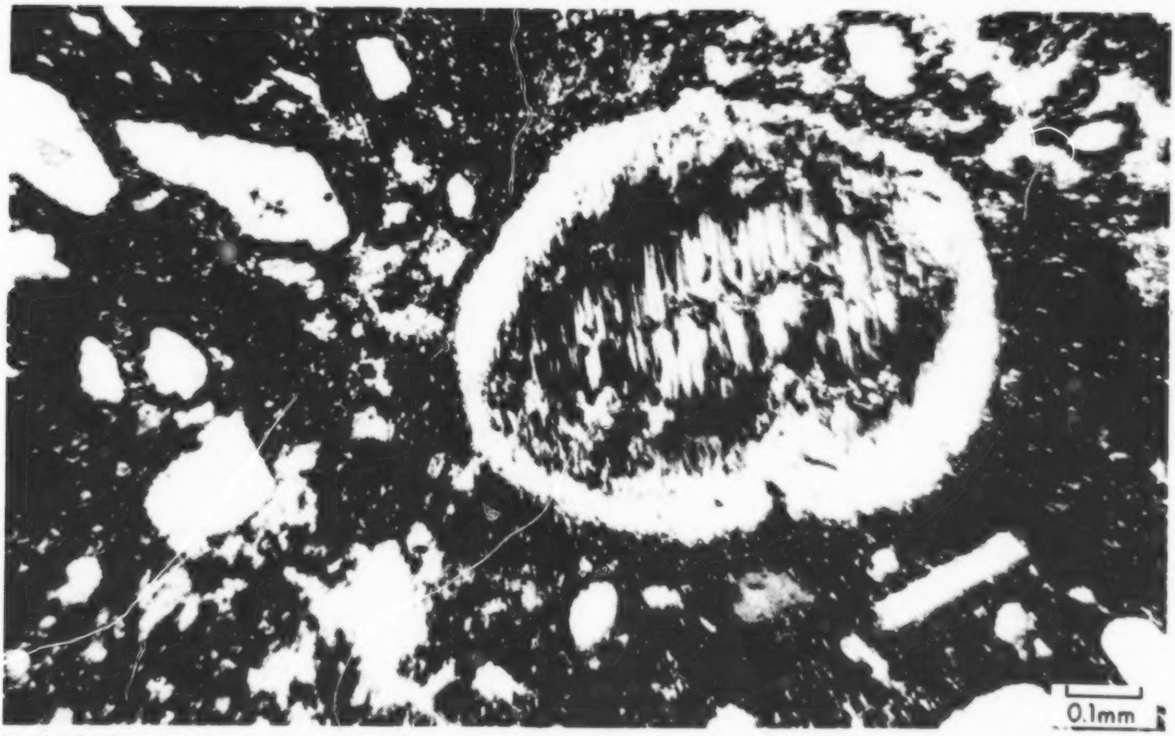

Plate 4-4-2. Cross diatreme serpentinized olivine macrocryst with phenocrystic serpentinized olivine, calcite (lower left) and phlogopite (lower right); field of view = 1.80 millimetres. XPL

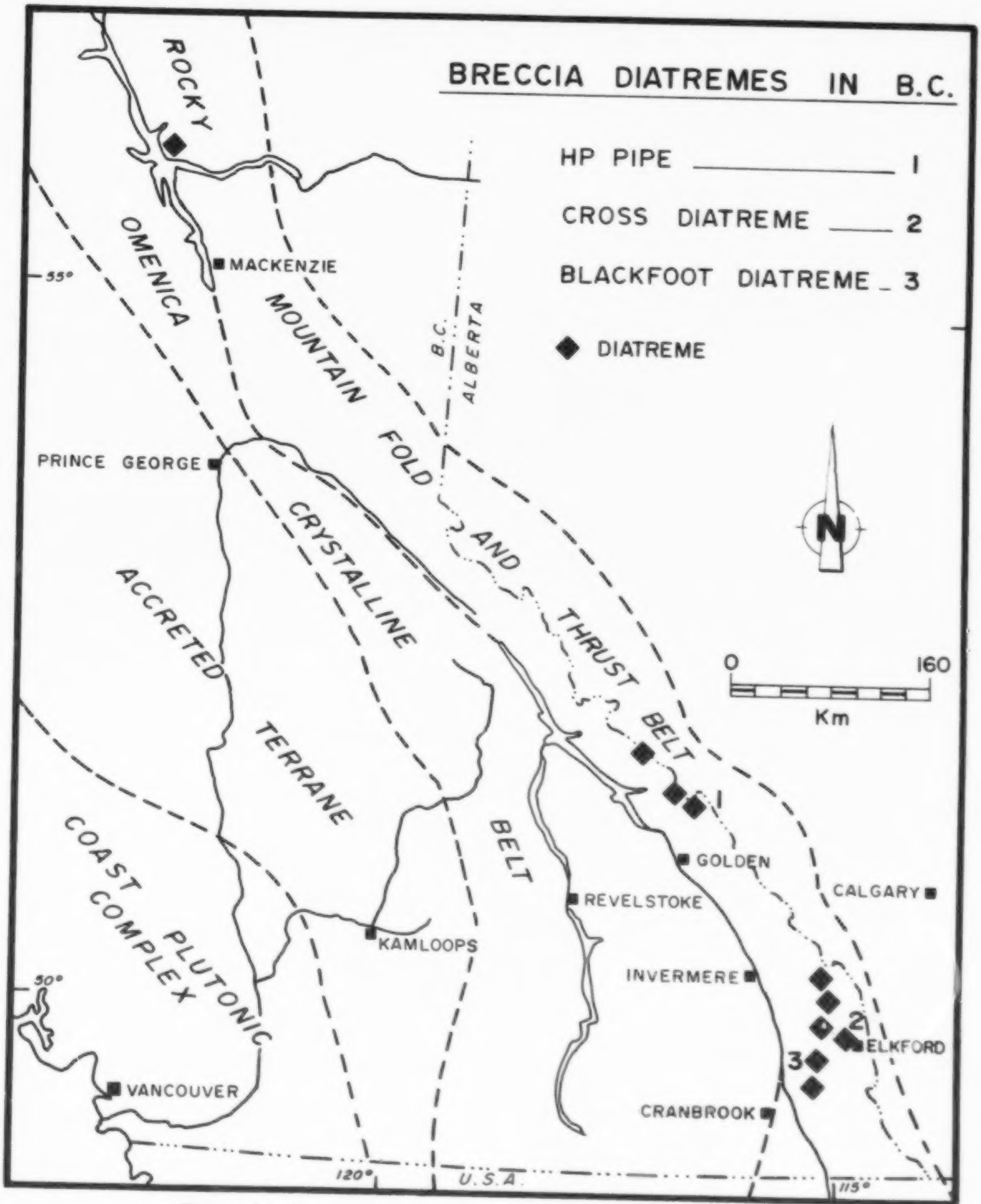
BRECCIA DIATREMES IN B.C.
HP PIPE — 1
CROSS DIATREME — 2
BLACKFOOT DIATREME — 3
DIATREME
ROCKY
MOUNTAIN
FOLD
AND
THRUST
BELT
OMENICA
CRYSTALLINE
BELT
ACCRETED
TERRANE
COAST
PLUTONIC
COMPLEX
MACKENZIE
PRINCE GEORGE
GOLDEN
CALGARY
REVELSTOKE
KAMLOOPS
INVERMERE
ELKFORD
CRANBROOK
VANCOUVER
B.C.
ALBERTA
U.S.A.
55°
50°
120°
115°
N
0
160
Km
1
2
3

Figure 4-4-1. Locations of breccia diatremes in British Columbia (after J. Pell).

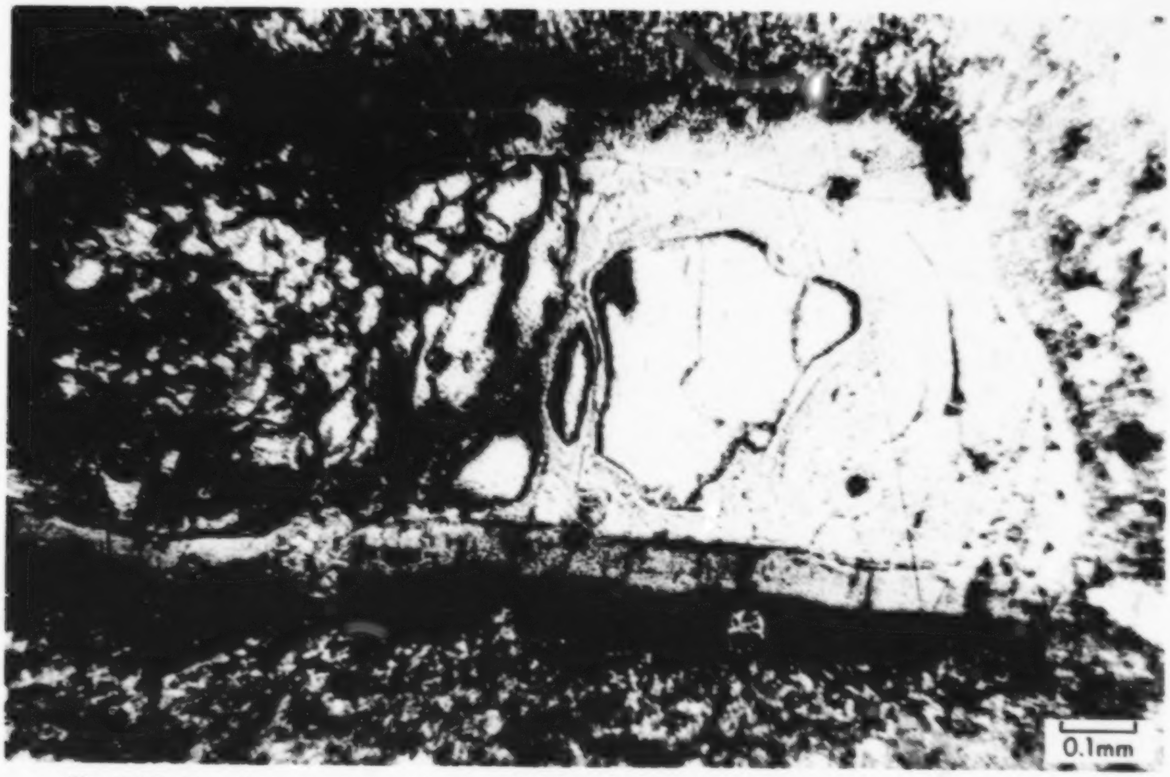

Plate 4-4-3. Cross diatreme macrocrystal garnet with kelyphitic alteration rim; field of view = 1.80 millimetres. PPL

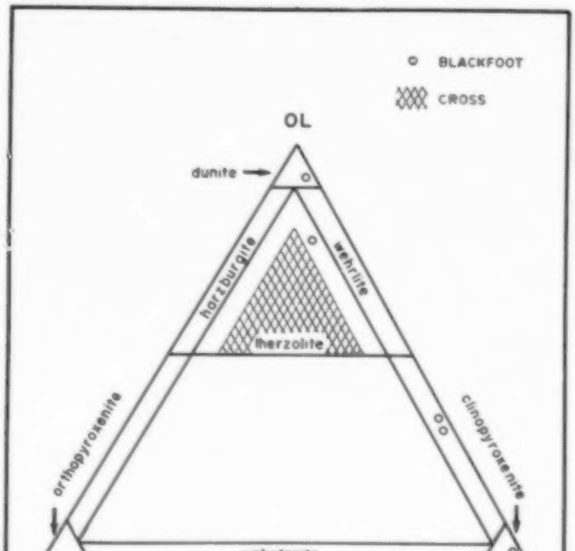

Figure 4-4-2. Peridotite ternary diagram for Cross and Blackfoot xenoliths.

The fine-grained groundmass is composed of serpentine and calcite with minor disseminated talc, pyrite and magnetite. Calcite is also present as medium-grained, irregular-shaped masses suggesting late stage crystallization. X-ray spectra show the calcite to be pure calcium-calcite. Opaque, disseminated microlites are concentrated in the larger calcite centres.

Secondary pyrite forms massive rims around calcite. Bright red hematite often forms envelopes around the pyrite and dendrites penetrating calcite aggregates.

THE BLACKFOOT DIATREME (82G/14)

INTRODUCTION

The Blackfoot diatreme outcrops east of Blackfoot Creek, 60 kilometres northeast of Cranbrook at latitude 49°58'30"N and longitude 115°17'00"W. Access is by helicopter or on foot from a logging road in the Blackfoot-Quinn Creek valley. The diatreme is elongate in shape, approximately 1000 metres in length with a maximum width of 400 metres (Pell, 1986). It is recessive and surrounded by steeply dipping limestone beds of the Ordovician-Silurian Beaverfoot-Brisco Formation (Pell, 1986).

The diatreme intruded the miogeoclinal succession prior to the Jurassic-Cretaceous Columbian Orogeny (Pell, 1986). Its age has not yet been established but its character is very similar to other diatremes which, on the basis of stratigraphic evidence, are thought to be pre-middle Devonian in age (Roberts *et al.*, 1980).

DESCRIPTION

The outcrop surface is very foliated and friable, light grey-green in colour and contains about 50 per cent inclusions consisting of angular limestone clasts and ultramafic xenoliths. Inclusions vary in size up to 10 centimetres in diameter. Xenoliths are predominantly hornblende clinopyroxenite, dunite and hornblendite. In contrast with the Cross diatreme, alteration is minimal, commonly affecting 4 to 15 per cent of the rock, although two samples exhibited entirely serpentinized olivine.

DETAILED PETROGRAPHY

In the clinopyroxenite xenoliths, the clinopyroxene is in the diopside range and the orthopyroxene tends toward enstatite. Pyroxenes show incipient alteration on the grain boundaries and penetration by fine-grained veinlets of acicular serpentine and talc. Some embayments and small pockets of serpentinization are present as alteration along cleavage planes. Sieving and disintegration are also observed in the centre of some pyroxenes. Brown pleochroic interstitial hornblende is also present.

Spinels are red to brown in colour and angular. They are fractured and embayed with talc and serpentine. X-ray spectra indicate a predominantly chromite composition with minor magnesium, aluminum substitution. Phenocrystic calcite is present in some samples both as a primary phase and replacing other minerals. Cleavage shows strain undulation. Olivine, present in both the clinopyroxenite and dunite, may be completely replaced by platy serpentine and calcite or remain unaltered. Olivine composition, measured optically, is Fo_{85}.

In the hornblendite xenoliths, large (0.5-1.0 centimetre), euhedral hornblende grains with tan pleochoism are in contact with smaller (0.1-1.4 millimetres size) interstitial, brown pleochroic hornblende. Ilmenite with pitted texture occurs predominantly in the hornblendite but is also interstitial to hornblende and clinopyroxene in other xenoliths. Trace amounts of disseminated pyrite, often rimmed by magnetite, are also present.

Rounded and anhedral xenocrystic quartz grains, with serrated edges, are seen in only two samples. Rare orthoclase grains show no reaction rims.

Glass lapilli, with opaque microlites clustered around the edges, are yellow in plane polarized light. Many contain impurities or are devitrified and can be very dark in plane light. Compaction in the form of elongation with fiamme structures is common. Vesiculation is still apparent (Plate 4-4-4). Devitrification and/or alteration takes the form of serpentine and calcite. Lapilli consitute about 25 to 30 per cent of the rock volume.

Clinopyroxene phenocrysts are in the diopside range and orthopyroxenes are almost pure enstatite. Pyroxene crystals tend to be rounded or anhedral with narrow rims of serpentine and calcite. Minor alteration is present along cleavage planes. Grains of pure calcium-calcite are usually square and show weak alteration with serpentine veinlets crosscutting and rimming some grains. Pyrite is euhedral and occasionally rimmed with magnetite. Spinel is anhedral, sometimes fractured and embayed and shows a range of colour from golden-orange to reddish-brown. X-ray spectra reveal a slightly more chrome-rich spinel than the xenolithic spinel.

The matrix, which makes up the majority of the sample volume, is a tuffaceous mixture of impure carbonate and serpentine with a fibrous, matted texture.

THE HP PIPE (82N/10)

INTRODUCTION

The HP diatreme is exposed near the nose of the Campbell Icefield, 50 kilometres northeast of Golden at latitude 51°41'30"N and longitude 116°57'00"W. It is accessible by helicopter. The outcrop, at an elevation of 2400 metres, measures about 45 by 35

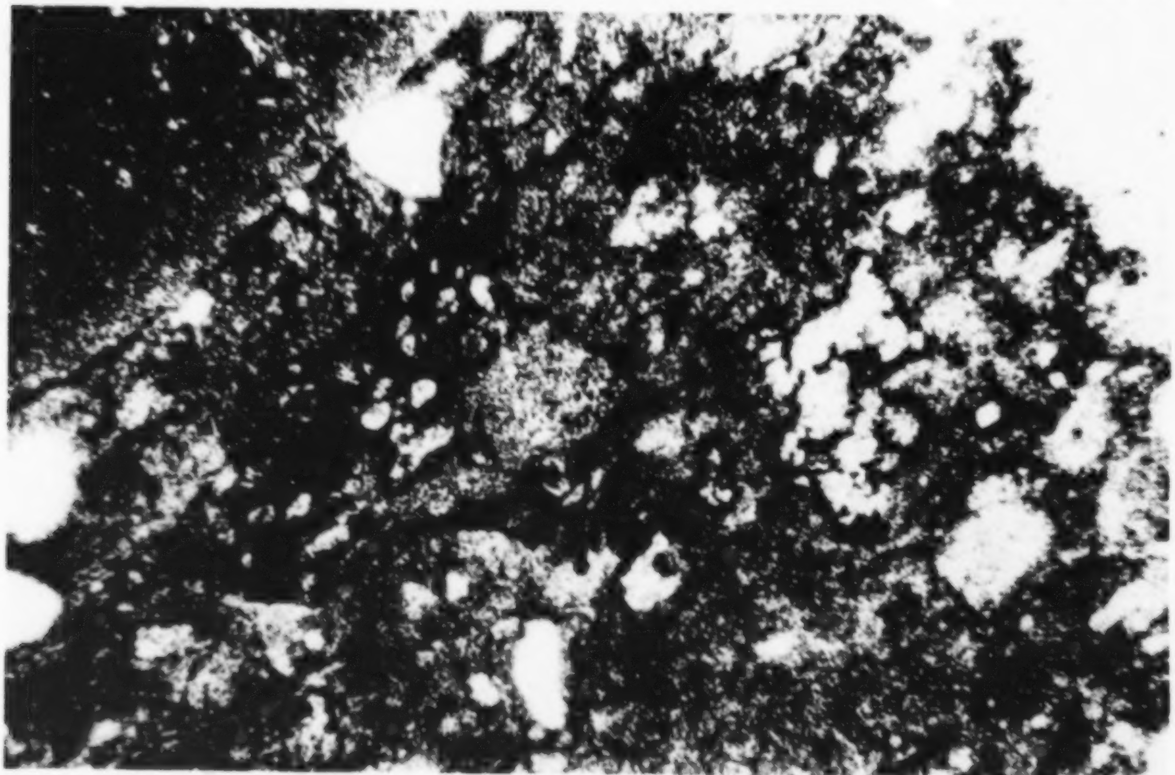

Plate 4-4-4. Blackfoot diatreme lapilli with opaque microlites and remnant vesicles; field of view = 1.10 millimetres. PPL

metres with topographic relief of less than 10 metres. The area was recently deglaciated, and the diatreme is almost completely exposed.

DESCRIPTION

The diatreme is slightly elongated north-south and associated with crosscutting dykes (Pell, 1986). The breccia phase is a foliated, pale green, coarse-grained rock with 40 per cent inclusions. They consist of angular and rounded, white, marmorized limestone clasts 1 to 3 centimetres long; round, black pyroxene xenocrysts up to 5 centimetres diameter; green diopside xenocrysts up to 2 centimetres diameter; biotite books up to 3 centimetres diameter; and some autoliths ranging in size from 5 to 20 centimetres. The dyke phase is fine grained, darker green and contains far fewer inclusions, but has more abundant and finer grained biotite.

DETAILED PETROGRAPHY

"Xenoliths" were sampled based on their field appearance of being dark, rounded, protruding features, though when examined more closely, they resembled more compact examples of the fine-grained phase and will therefore be referred to as nodules.

The nodules contain less than 25 per cent phenocrysts of biotite, garnet, pyroxene, calcite and spinel. The biotite is partially chloritized and moderately altered to serpentine and calcite. Acicular opaques are exsolved along cleavage planes in the biotite. Biotite X-ray spectra show high iron:magnesium ratios and occasionally zoning to iron-rich rims. Garnets are light green or brown in colour. They show a partly euhedral outline in contact with calcite (Plates 4-4-5 and 4-4-6) and an irregular contact with biotite (Plate 4-4-6). Optical characteristics and X-ray spectra indicate that the brown garnet is melanite, a titanium-bearing andradite, and the green garnet is titanium-free andradite. The pyroxenes are diopside and enstatite. They show textures ranging from good euhedral outlines to edge resorption and cleavage plane alteration. Calcite exhibits good crystal form and X-ray spectra indicate a pure calcium-calcite. Spinels are either a titanium-bearing magnetite or a red-brown chromite with minor amounts of aluminum, magnesium and titanium.

The nodule groundmass constituents are fine-grained serpentine, calcite, talc, chlorite and biotite.

The coarse-grained breccia phase contains macrocrysts of pyroxene, biotite, devitrified lapilli and altered phenocrysts of pyroxene, garnet, biotite and integral spinels. Clinopyroxenes are in the diopside-augite and titanaugite range and show margin alteration, alteration blebs and cleavage plane alteration to serpentine and calcite. The more iron-rich augite contains disseminated pyrite grains. Rims of opaques in a chlorite matrix are also found to envelope the grains. The orthopyroxene is enstatite and shows less alteration than the diopside and augite. Garnets form small euhedral crystals with interstitial calcite (Plate 4-4-7). X-ray spectra show the garnets to be titanium-bearing melanite similar to the nodular garnets. Biotite with tan pleochroism exhibits moderate corrosion. Spinels are angular and reddish-brown in colour.

The groundmass of the coarse breccia phase is comprised of biotite, melanite, pyrite, calcite and mangnesium-iron alteration minerals, serpentine and chlorite. Randomly oriented, acicular tan biotite makes up 30 to 40 per cent of the groundmass in some specimens and is not limited to those containing phenocrystic biotite. Melanite occurs as small aggregates (0.15 millimetre) of tiny euhedral crystals (0.02 millimetre) and constitutes 20 per cent of the rock volume. Melanites also outline devitrified lapilli (Plate 4-4-8).

The fine-grained dyke phase contains no orthopyroxene or relict lapilli. The macrocryst population consists of clinopyroxene and biotite while the phenocrysts comprise both these minerals together with garnet and spinel. Clinopyroxene is of the diopside and augite varieties and is highly altered and largely replaced by talc and calcite. Garnet, a titanium-free andradite, forms small, euhedral, pale green crystals and may be surrounded by a ring of relatively large, randomly oriented biotites. Partially altered biotite with serrated ends also shows compositional zoning at the ends, termed "battlemented" iron-rich ends (Williams *et al.*, 1982). Spinel, angular and red-brown in colour, is present in trace amounts. The groundmass is comprised of andradite clumps, biotite, serpentine, talc and chlorite.

DIATREME COMPARISONS

The age of emplacement of the diatremes spans a wide time range in the Paleozoic. The Cross diatreme, intruding Pennsylvanian sedimentary rocks, has been dated using rubidium/strontium ratios at 240 million years (Smith, 1983) and 244 million years (Grieve, 1981) placing it near the Permo-Triassic boundary. Rubidium/strontium ratios in the HP pipe, which intrudes Cambro-Ordovician sedimentary rocks, date its intrusion at 347 million years (R.L. Armstrong, personal communication, 1986) placing it near the Devonian-Mississippian boundary. The Blackfoot diatreme intrudes Ordovician-Silurian rocks and closely resembles other southern British Columbian pipes which exhibit synsedimentary phases with Ordovician-Silurian strata (J. Pell, personal communication, 1986). Radiometric dating has not yet been completed.

Where ultramafic xenoliths occur, they vary in composition from one diatreme to another. Only the Cross and Blackfoot diatremes have ultramafic xenoliths which can be compared on a peridotite ternary diagram (Figure 4-4-2). The HP pipe has compacted nodules of diatreme material. The amount of ortho versus clinopyroxene in Cross xenoliths cannot be determined precisely due to pervasive serpentinization; a general field of spinel lherzolite is indicated. The majority of Blackfoot xenoliths are classified as hornblende clinopyroxenite.

Macrocrysts, where they occur, show no overlap among the diatremes except for the biotite mineral group. Cross diatreme macrocrysts consist of completely serpentinized olivine, disintegrating garnet of the pyrope-almandine-grossular variety and titanium-bearing phlogopite. Macrocrysts from HP are diopside, augite, titanaugite, enstatite and biotite. The Blackfoot diatreme has no macrocrysts.

The phenocryst populations in the three diatremes show many differences (Table 4-4-1). The HP phenocrysts are combined from all three phases (nodular, coarse-grained breccia and fine-grained dyke phases) as they are assumed to be consanguineous. Spinel is common to all three diatremes. Unambiguous clinopyroxene is present in Blackfoot and HP. The pyroxene phenocrysts at Cross are

TABLE 4-4-1.
COMPARATIVE PHENOCRYST ASSEMBLAGES

Mineral	Cross	Diatreme Blackfoot	HP
Olivine	x	o	o
Phlogopite	x	o	o
Biotite	o	o	x
Spinel (chromite)	x	x	x
Magnetite	o	o	x
Calcite	o	o	x
Clinopyroxene	o	x	x
Orthopyroxene	o	o	x
Hornblende	o	x	o
Garnet (melanite)	o	o	x

Note: x = present, o = absent.

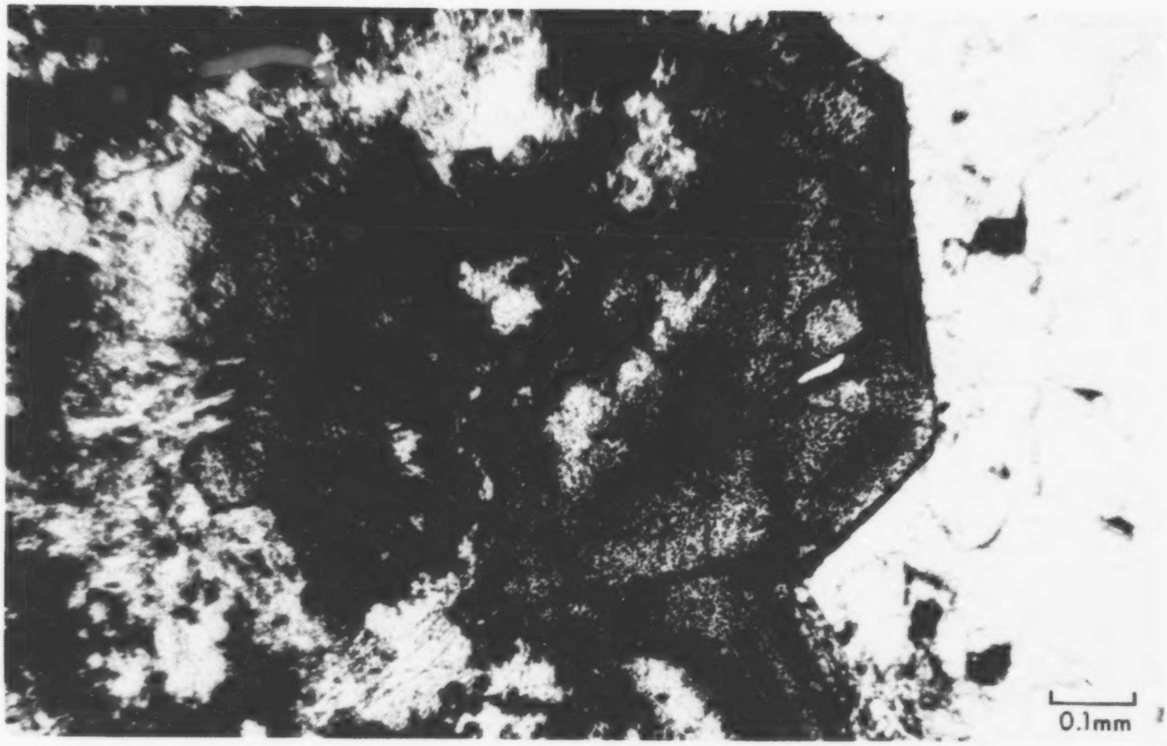

Plate 4-4-5. HP diatreme nodular brown melanite garnet with calcite (right); field of view = 1.4 millimetres. PPL

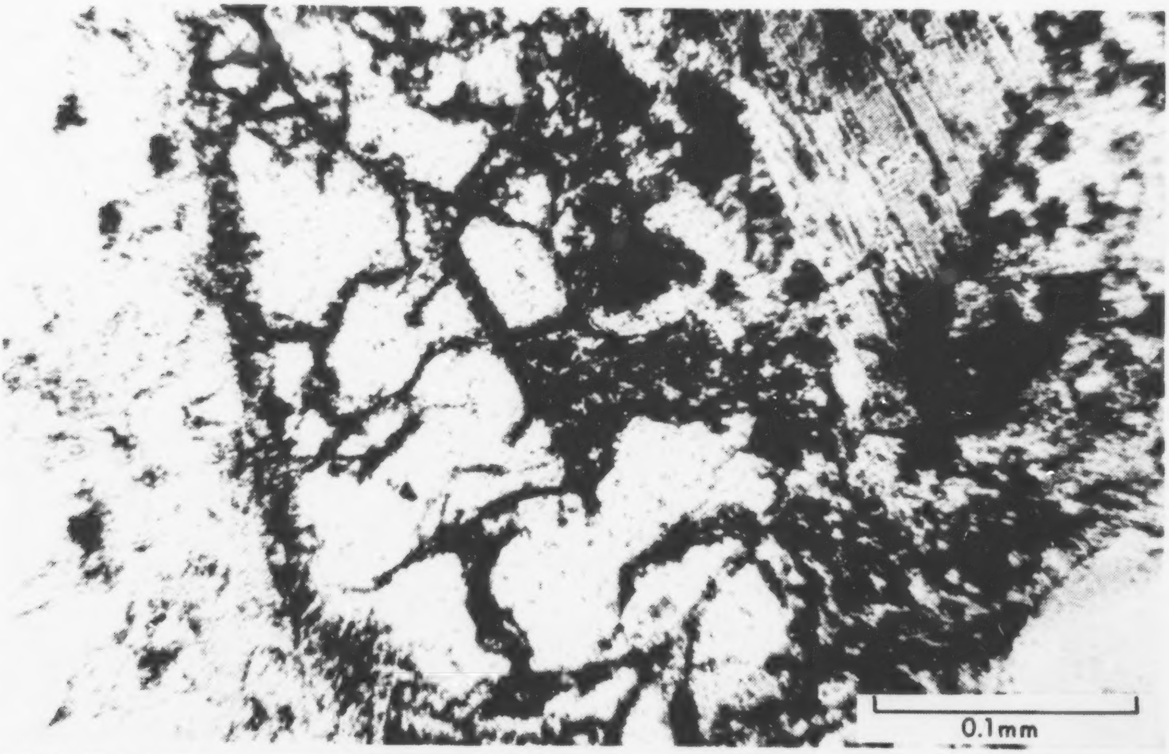

Plate 4-4-6. HP diatreme nodular green andradite, calcite (left) and chloritized biotite (upper right); field of view = 0.5 millimetre. PPL

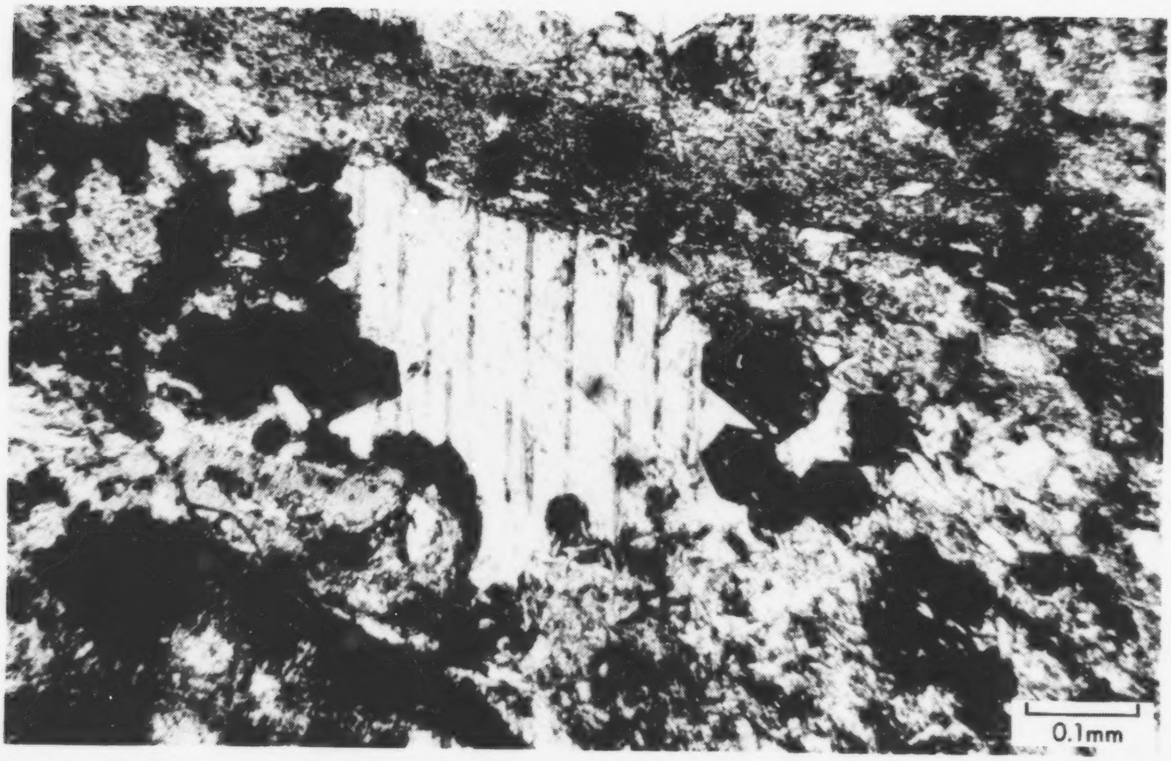

Plate 4-4-7. HP diatreme coarse-grained breccia phase, small euhedral melanite microgarnets with interstitial calcite, all in chloritized groundmass; field of view = 1.10 millimetres. PPL

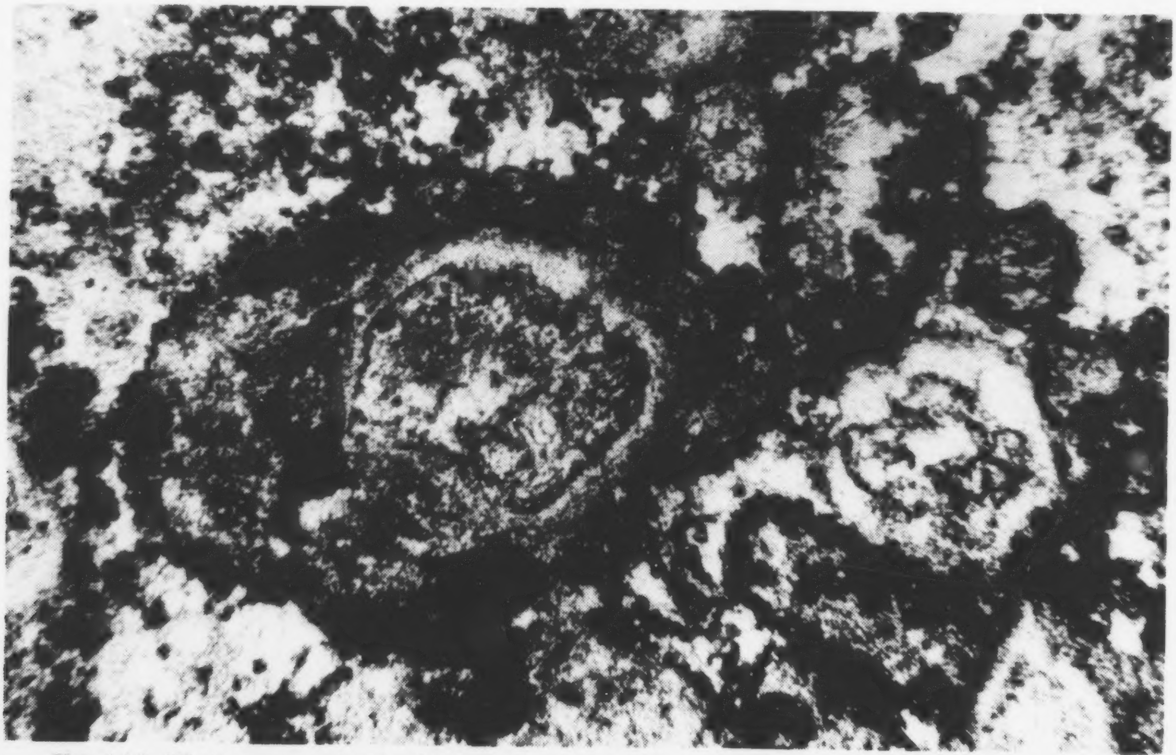

Plate 4-4-8. HP diatreme groundmass melanite garnets outlining devitrified lapilli; field of view = 1.40 millimetres. PPL

TABLE 4-4-2.
COMPARATIVE GROUNDMASS MINERALOGY

Mineral	Diatreme	
	Cross	HP
Serpentine	x	x
Calcite	x	x
Talc	x	x
Pyrite	x	x
Magnetite	x	o
Biotite	o	x
Chlorite	o	x
Garnet (melanite)	o	x

Note: x = present, o = absent.

too serpentinized to allow distinctions to be made between orthopyroxene and clinopyroxene.

The Cross and HP diatremes are considered to have true igneous groundmasses of different compositions (Table 4-4-2). Some samples from HP also contain relict glass lapilli. Blackfoot is a tuffaceous diatreme with a fine-grained impure carbonate matrix of uncertain origin. Rare juvenile glass lapilli, some devitrified, together with rare phenocrysts make up the igneous component.

The three diatremes fall into distinct petrologic provinces. Only Cross conforms to the kimberlite definition outlined by Clement *et al.* (1984), and falls into the serpentine kimberlite classification of Skinner and Clement (1979). Blackfoot, with glass, pyroxene, hornblende and calcite, shows affinity to a limburgite as defined by Williams, Turner and Gilbert (1982). The HP diatreme and related dykes represent a unique assemblage; they contain melanite which is commonly associated with alkaline igneous rocks (Williams *et al.*, 1982; Deer *et al.*, 1962) but a classification for the complete assemblage remains elusive.

Varying degrees of serpentine and calcite alteration are common to all three diatremes. Cross is characterized by pervasive deuteric alteration of the iron-magnesium minerals, olivine, pyroxene and, to a lesser extent, garnet. Serpentinization and carbonatization occurred during the late stages of magmatic crystallization. Secondary alteration is manifest as pyrite rims, red hematite envelopes and dendritic hematite. Blackfoot shows minimal serpentinization and carbonatization of olivine. Talc replaces olivine, but pyroxene remains largely unaffected. Secondary alteration effects are not present at Blackfoot. The HP diatreme exhibits moderate deuteric alteration of pyroxene and to a lesser extent biotite, to serpentine, talc and calcite. The melanite garnets remain essentially unaltered. Secondary alteration takes the form of chloritization of biotite.

The mineral chemistry of biotites, spinels and garnets from the three diatremes has been compared. Biotite and phlogopite appear only in Cross and HP diatremes and fall into distinct chemical regions (Figure 4-4-3). To compare their mineral chemistries semi-quantitatively, the heights of the iron and mangnesium peaks of the printed X-ray spectra were measured. Ratios of (magnesium x 100)/(iron + magnesium) were calculated and compared to measurements of magnesium.

Chrome spinels are present in all three diatremes and in all xenoliths and nodules. A comparison of the xenolith and nodular spinel aluminum content was made using the ratio (aluminum x 100)/(aluminum + chromium) plotted against aluminum (Figure 4-4-4). Spinel chemistry shows varying aluminum ratios suggesting either that the Cross diatreme occupies the highest pressure-temperature space of the three diatremes, or merely a variation in the bulk chemistry.

Garnets are not present at Blackfoot. Pyrope-almandine-grossular garnets are seen at Cross whereas andradites characterize

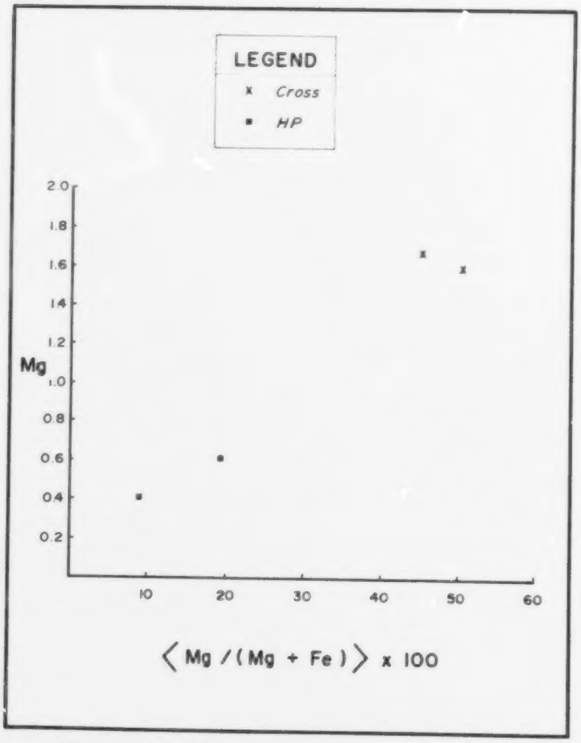

Figure 4-4-3. Magnesium component in biotite for Cross and HP diatremes.

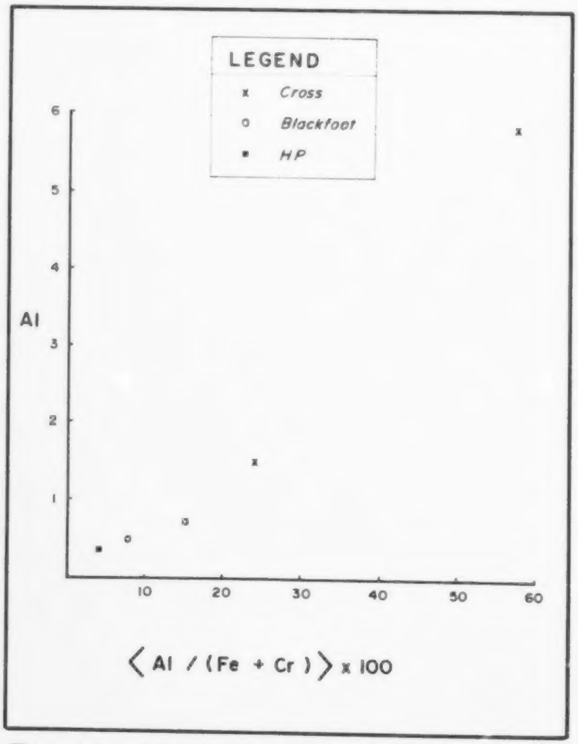

Figure 4-4-4. Aluminum component in chrome spinels both in the groundmass and in the xenoliths.

HP. Garnet stability field diagrams (for example, Meagher, 1980) suggest that the Cross garnets may occupy a higher pressure region than the HP andradite, though there is some possibility of overlap.

It is concluded from petrographic and SEM analysis that these three ultramafic breccia diatremes, which appear similar in the field, occupy quite distinct petrologic provinces.

ACKNOWLEDGMENTS

I would like to thank Drs. J.K. Russell, Jennifer Pell, Barbara Scott-Smith, Mr. J. Knight and Ms. J. Flood who provided expert advice, guidance and assistance in support of this study. Funding for summer fieldwork and generous technical support throughout to this project was provided by the British Columbia Ministry of Energy, Mines and Petroleum Resources under the Canada/British Columbia Mineral Development Agreement.

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THE ALEY CARBONATITE COMPLEX
NORTHERN ROCKY MOUNTAINS, BRITISH COLUMBIA*
(94B/5)

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Department of Geological Sciences
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INTRODUCTION

The Aley carbonatite complex was discovered in 1980 and staked by Cominco Ltd. in 1982 (Pride, 1983) for its niobium potential. The property is located 140 kilometres north-northwest of Mackenzie, on the east side of Williston Lake, at latitude 56°27′ north, longitude 123°45′ west.

A brief account of the geology was presented by Pell (1986a, 1986c). This contribution is an outline of an M.Sc. thesis recently completed at The University of British Columbia by the author (Mäder, 1986).

GEOLOGY

The Aley carbonatite complex intruded Cambrian sediments (Figure 4-5-1) of the continental margin of ancient North America near the shelf/off-shelf boundary prior to the formation of the northern Rocky Mountains (potassium-argon ages of 340 to 350 million years) (Pell, 1986c; Pell, this volume). The youngest unit affected by the intrusion is the Skoki volcanic sequence (mid-Ordovician?).

The carbonatite complex is oval in outline, 3 to 3.5 kilometres in diameter and occupies an area of about 7 square kilometres. The body is cylindrical in the third dimension with a nearly vertical axis and has probably been only slightly tilted from its original orientation.

The complex consists of an older, outer ring of metasomatically altered syenite that occupies one-third of the volume. The core is formed by dolomite carbonatite with minor calcite carbonatite "sweats" and some rare-earth carbonate-rich "sweats". Rare-earth carbonate-rich ferrocarbonatite dykes intrude the contact aureole. The contact aureole is composed of recrystallized carbonate rocks characterized by a cream to brownish weathering colour, but is little affected by metasomatism and shows no indication of high-temperature contact metamorphism.

The relationship of nearby lamprophyric dykes and the Ospika diatreme (Pell, 1986b; Pell, this volume) to the carbonatite complex is unclear.

The Aley complex and its contact aureole are part of an imbricate thrust sheet of the northern Rocky Mountains, bounded to the west by a high-angle thrust fault juxtaposing Cambrian rocks of the contact aureole against unmetamorphosed Silurian rocks (Figure 4-5-1). The Silurian rocks form part of the tectonically thinned eastern limb of a tight anticline with a Cambrian core to the west. This structural element is dissected by faults striking at high angles to the Rocky Mountain trend. Along the eastern side of the complex a tectonically thinned, reversed stratigraphic section, with a set of subparallel lower angle thrust faults, is thrust onto an imbricate sheet containing Silurian rocks (to the east of the area mapped). Parts of the carbonatite complex may be faulted out above and below the exposed level. The fault zones along the eastern and western side of the Aley complex are mapped as two branches of the Burden thrust (Thompson, 1978).

STRUCTURES RELATED TO THE EMPLACEMENT OF THE COMPLEX

The inner part of the contact aureole forms an annular, cylindrical, ductile shear zone evidenced by "chocolate-tablet" boudinage, shear folds and locally by sheath folds. Horizontal and vertical components of extension near the contact are in the order of 200 to 400 per cent. The ductile shear zone suggests that doming was the major mechanism of emplacement. This is consistent with circular, steeply dipping structural trends in the carbonatite core, outlined by a cleavage and mineral layering (apatite, magnetite, pyrochlore, fersmite, biotite and amphibole). Temperatures within the contact aureole, deduced from calcite-dolomite geothermometry (250°C to 350°C) and metamorphic phase assemblages (≤400°C), further support the view that at least part of the complex was emplaced at subsolidus temperatures.

MINERALOGY AND MINERAL CHEMISTRY

Approximately 50 mineral species are identified in the four major rock types of the Aley carbonatite complex (Table 4-5-1). The list of minerals is still incomplete. Niobium-rich phases of economic interest include fersmite, pyrochlore and columbite.

Tables 4-5-2, 4-5-3 and 4-5-4 list averaged microprobe analyses of selected minerals.

PETROGRAPHY

DOLOMITE CARBONATITE

Fersmite and pyrite-bearing dolomite-apatite-carbonatite: Different degrees of deformation and alteration resulted in a variety of textures. Fresh dolomite carbonatite has a large range of grain sizes (0.1 to 4 millimetres) with a granoblastic interlocking texture, almost idiotopic in some parts. Apatite occurs as prismatic crystals or disk-like flattened aggregates oriented parallel to the planar fabric. Fersmite forms fibrous to fine-grained aggregates replacing euhedral pyrochlore (cubic). Primary fersmite (orthorhombic) is rare. Columbite is observed replacing fersmite.

Alteration of dolomite carbonatite includes extensive chloritization and minor silicification of narrow fracture zones with relatively abundant fersmite and/or pyrochlore. Metallic black, granular aggregates are widespread and consist of chlorite-rutile mixtures or dolomite with thin niobian rutile lamellae grown along the rhombohedral cleavage.

CALCITE CARBONATITE

Magnetite, pyrochlore, amphibole, pyrite-bearing calcite-apatite-carbonatite: Calcite carbonatite typically displays a strong

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

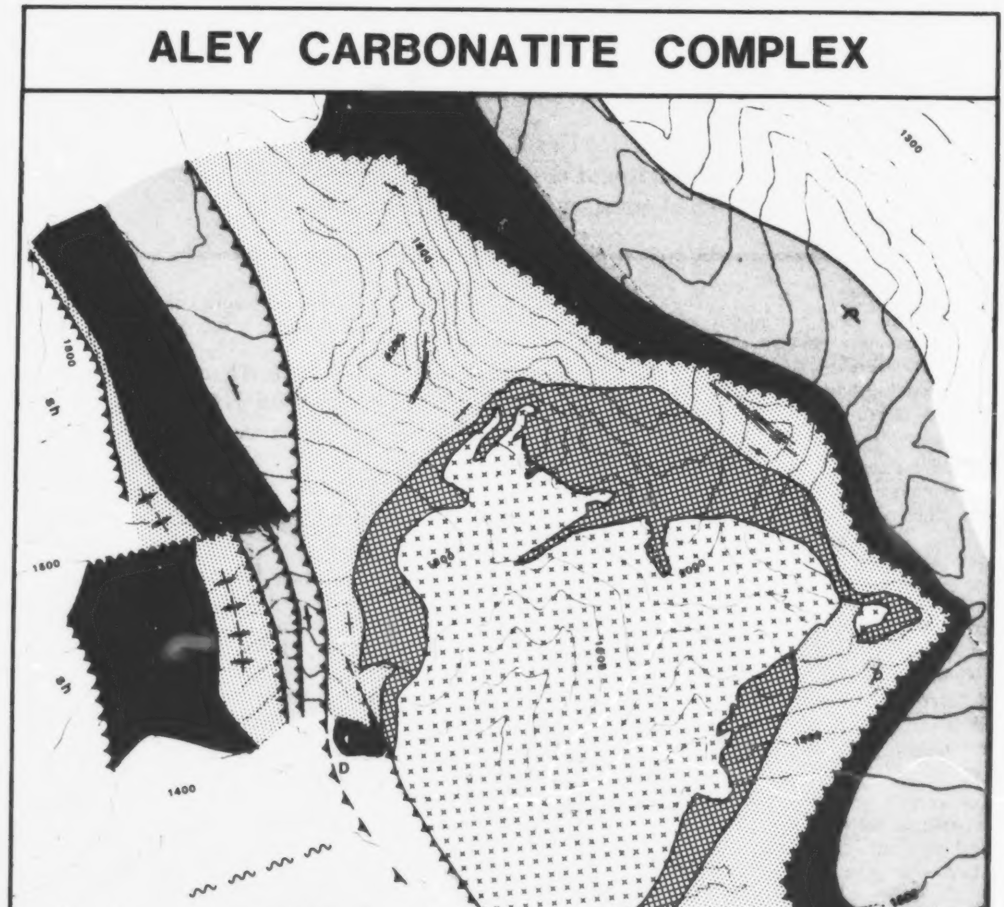
ALEY CARBONATITE COMPLEX
1300
1800
sh
1600
sh
1400
D
N
1200
2000
1900
1800
sh
B.C.
ALEY
Williston Lake
ALTA
Vancouver
U.S.A.
Sil
ROAD RIVER GR (dol)
Ord-Sil
ROAD RIVER GR (sst,sh)
Ord
ROAD RIVER GR (sh)
Ord
SKOKI FM (dol,volcanics)
Camb ?
KECHIKA FM (lst,marl,silt)
100 m contours
1 km
ALKALI-SYENITE
CARBONATITE
Dev
RARE-EARTH CARB. DIKES
D
DIATREME (OSPIKA PIPE)
U. MADER

Figure 4-5-1. Geological map of the Aley carbonatite complex based in part on geological mapping by Cominco Ltd.

TABLE 4-5-1 MINERALOGY

Mineral	Mineral Class	Occurrence
dolomite-ankerite	carbonate	cd, re1, re2, au
calcite	carbonate	cc, au, sy
strontianite (?)	carbonate	re1, cd
alstonite (barytocalcite) (?) BaCa $(CO_3)_2$	carbonate	re1
aragonite-strontianite ss (?)	carbonate	re1, sy
Sr-Ca-Ba carbonate (?)	carbonate	re1
burbankite (Na, Ca, Sr, Ba, LREE)$_6$ $(CO_3)_5$	carbonate	re1
ancylite LREE (Ca, Sr) $(CO_3)_2(OH)\cdot H_2O$	carbonate	re1, sy
cordylite Ba (LREE, Ca, Sr)$_2(CO_3)_3F_2$	carbonate	re1, cd
huanghoite BaLREE $(CO_3)_2F_2$	carbonate	re, red
bastnasite LREE $(CO_3)F$	carbonate	red
Ce-Ba-La-Ca carbonate (?)	carbonate	re1
Ca-La-Nd carbonate (parisite) (?)	carbonate	re2
LREE carbonate (calkinsite, lanthanite) (?)	carbonate	au
Ca-Sr-Ba-Ce carbonate (?)	carbonate	re1, cc
apatite	phosphate	cd, cc, re1, sy
monazite (LREE, Th, Ca)PO_4	phosphate	cd
rhabdophane (LREE)$PO_4\cdot H_2O$	phosphate	au
cheralite (Th, Ca, LREE)PO_4	phosphate	cd
rutile	oxide	cd
hematite	oxide	cd, cc, au
magnetite	oxide	cc
baddeleyite ZrO_2	oxide	cc
thorianite ThO_2	oxide	cd
pyrochlore $(Na, Ca)_2Nb_2O_6(OH, F)$	oxide	cc
fersmite (Ca, Na) $(Nb, Ta, Ti)_2(O, OH, F)_6$	oxide	cd, (cc)
columbite Fe $(Nb, Ta)_2O_6$	oxide	cd
zirkelite (?) (Ca, Th)Zr $(Ti, Nb)_2O_7$	oxide	cc
Ta-Ca zirconate-niobate	oxide	cd
quartz	silicate	sy, cc, cd, re2
albite	silicate	sy, cd
potassium feldspar	silicate	sy, re1
chlorite	silicate	cd, cc, di, la
serpentine	silicate	cd
biotite	silicate	cc, di, la
muscovite, phlogopite	silicate	au
magnesio-arfvedsonite $Na_3\ (Mg, Fe)_4Fe^{3+}Si_8O_{22}(OH, F)_2$	silicate	sy
richterite $Na_2Ca\ (Mg, Fe^{2+}, Fe^{3+})_5Si_8O_{22}(OH, F)_2$	silicate	cc
aegirine (Na, Ca) $(Fe^{3+}, Mg, Fe^{2+}, Ti)Si_2O_6$	silicate	sy
lorenzenite $Na_2Ti_2Si_2O_9$	silicate	sy
zircon	silicate	cd
thorite (huttonite)	silicate	cd
cerite (?)	silicate	au
Mg silicate	silicate	cc
barite	sulphate	re1, re2
pyrite	sulphide	cd, re1, re2, cc
galena	sulphide	re1, cd
chalcopyrite	sulphide	sy

List of minerals identified in the Aley carbonatite complex with contributions by P.C. LeCouteur and K.R. Pride (Cominco Ltd.): LREE = light rare-earth elements (La, Ce, Nd, Pr); ss = solid solution; cd = dolomite carbonatite; cc = calcite carbonatite; re1 = rare-earth element carbonatite dykes (north ridge); re2 = barite-rich rare-earth element carbonatite dykes (northwest ridge); red = rare-earth-rich "sweats" within the carbonatite; sy = "syenite"; au = metamorphic rocks of the contact aureole.

TABLE 4-5-2
MINERAL CHEMISTRY, ELECTRON MICROPROBE ANALYSES OF CARBONATE MINERALS

Wt %	Do	Cc	Ank
CaO	32.11	53.16	28.98
MgO	17.03	0.55	14.12
FeO[1]	3.50	0.14	7.29
MnO	0.33	0.21	3.66
SrO	0.00	0.80	0.24
CO_2[2]	46.14	42.87	25.00
Total	99.11	97.72	99.29
Mol %		**Normalized Analyses**	
$CaCO_3$	54.61	97.39	50.54
$MgCO_3$	40.31	1.40	34.26
$FeCO_3$	4.64	0.20	9.93
$MnCO_3$	0.44	0.30	5.04
$SrCO_3$	0.00	0.79	0.23
Total	100.00	100.00	100.00

[1] total iron.

[2] calculated.

Do = dolomite from dolomite carbonatite, Cc = calcite from calcite carbonatite, Ank = ankerite from rare-earth carbonatite dyke.

Samples were analysed with an ARL-SEMQ (University of Calgary) operated at 15 keV and 0.15 µA with a split beam.

TABLE 4-5-3
MINERAL CHEMISTRY, ELECTRON MICROPROBE ANALYSES OF ARFVEDSONITE AND AEGIRINE

	Wt %		Normalized Analyses[1]		
	Arf	Aeg		Arf	Aeg
SiO_2	54.66	52.71	Si	8.09	1.98
TiO_2	0.21	5.82	Ti	0.02	0.16
Al_2O_3	0.13	0.52	Al	0.02	0.02
FeO[2]	11.00	23.24	Fe	1.36	0.66
MgO	16.31	2.55	Mg	0.12	0.01
MnO	0.94	0.37	Mn	3.60	0.14
CaO	2.45	1.25	Ca	0.39	0.05
Na_2O	8.34	13.51	Na	2.39	0.98
K_2O	1.78	0.01	K	0.34	0.00
BaO	0.01	0.03	Ba	0.00	0.00
F	2.45	0.01	F	1.15	0.00
H_2O[3]	0.70		OH	0.69	
			O	22.16	6.00
Total	98.99	100.01	O,OH,F	24.00	

[1] arfvedsonite normalized to 24 (O, OH, F), aegirine normalized to 6 oxygens.

[2] total iron.

[3] estimated.

Arf = arfvedsonite from "syenite", Aeg = aegerine from "syenite".

Samples were analysed with an ARL-SEMQ (University of Calgary) operated at 15 keV and 0.15 µA.

TABLE 4-5-4
MINERAL CHEMISTRY, ELECTRON MICROPROBE ANALYSES OF PYROCHLORE

	Wt %		Formula $A_2B_2O_6$ (OH,F)		
	Core	Rim		Core	Rim
Nb_2O_5	61.12	69.08	Nb (B)	1.77	1.96
Ta_2O_5	0.18	0.32	Ta (B)	0.01	0.01
ZrO_2	1.44	0.06	Zr (B)	0.04	0.00
TiO_2	3.86	0.82	Ti (B)	0.18	0.04
			Total B	2.00	2.01
CaO	16.38	16.33	Ca (A)	1.12	1.09
Na_2O	7.34	9.16	Na (A)	0.92	1.11
FeO	0.36	0.00	Fe (A)	0.02	0.00
MnO	0.10	0.01	Mn (A)	0.00	0.00
La_2O_3	0.07	0.04	La (A)	0.00	0.00
Nd_2O_3	0.22	0.20	Nd (A)	0.01	0.01
Ce_2O_3	0.89	0.13	Ce (A)	0.02	0.00
ThO_2	3.44	0.26	Th (A)	0.06	0.00
UO_2	0.01	0.00	U (A)	0.00	0.00
Total	95.41	96.41	Total A	2.15	2.21

Analyses by Dr. G. Perrault, Ecole Polytechnique, Montreal, Quebec.

parallel fabric marked by a cleavage and mineral layering. Calcite forms a granoblastic-polygonal texture and is much finer grained (0.05 to 0.2 millimetre) than dolomite carbonatite. Apatite forms prismatic crystals or disk-like flattened aggregates aligned parallel to the fabric. Biotite forms hexagonal, prismatic, equant crystals associated with magnetite and/or pyrochlore. Pyrochlore displays its octahedral habit and is zoned with rims relatively enriched in niobium. Amphibole of richterite composition is fibrous to acicular and aligned parallel to the fabric. At least part of the amphibole formed metasomatically near the contact with the "syenitic" ring. Accessory minerals include zircon and rare baddeleyite associated with zirkelite.

Calcite carbonatite is more resistant to weathering than dolomite carbonatite. Small amounts of chlorite and secondary quartz may form in zones of higher strain.

RARE-EARTH CARBONATITE DYKES

Two dyke swarms occur in the contact aureole of the complex (Figure 4-5-1). The dykes across the north ridge are characterized by orange, ovoid aggregates of rare-earth carbonates (mostly burbankite); those across the northwest ridge have dispersed rare-earth carbonates, abundant barite and secondary quartz.

Burbankite, cordylite and huanghoite are probably primary igneous rare-earth carbonates whereas the hydrous carbonates and various calcium-strontium-barium carbonates are part of the alteration assemblage.

RARE-EARTH-RICH "SWEATS" WITHIN THE COMPLEX

Minor rare-earth carbonate-rich differentiates occur at a few localities within the complex. Large (centimetre-scale) irregular crystal aggregates of huanghoite and bastnaesite occur in a dolomite matrix.

METASOMATICALLY ALTERED SYENITE

Aegirine and arfvedsonite-bearing albite-quartz rock to quartz-bearing albite-aegirine-arfvedsonite rock: This unusual rock displays a great compositional and textural variety. Relict microsyenite textures indicate a primary igneous origin as an

TABLE 4-5-5
WHOLE ROCK GEOCHEMISTRY, X-RAY FLUORESCENCE ANALYSES OF SELECTED WHOLE ROCK SAMPLES

Wt %	cd	cc	re1	re2	sy1	sy2
SiO_2	0.50	2.17	0.65	7.30	66.36	53.00
Al_2O_3	0.26	0.02	0.21	0.67	4.28	1.33
TiO_2	<0.01	0.04	0.01	0.04	0.68	0.35
FeO (tot)	2.95	8.41	10.49	12.00		
FeO		0.97				
Fe_2O_3		1.32				12.91
MnO	0.26		4.11	3.30	0.27	0.35
MgO	17.34	5.85	11.29	7.91	2.55	16.00
CaO	32.89	45.69	28.14	24.59	4.05	3.50
Na_2O	0.63	0.48	1.13	0.79	7.79	7.71
K_2O	0.02	0.05	0.04	0.06	0.24	1.15
P_2O_5	1.74	4.60	0.14	0.09	0.70	0.68
S	0.01	0.21	0.06	1.11	0.02	
Ba			0.69	7.74		
LOI	43.52	38.71	42.55	33.31	0.84	
Total	95.70	99.90	98.77	98.74	98.86	97.88
ppm						
Nb	490	3290	<5	29	71	280
Zr	66	600	580	96	270	390
Y	41	97	13	96	6	21
Sr	360	5280	5550	700	300	670
U	<9	<20	21	<10	<9	<20
Rb	4	<20	<4	<4	<3	<20
Th	130	65	28	840	<7	<20
Ta	18	<20				
Ba	39	315			1340	540
La	310	315	2670	2290	63	235
Ce	750	710	4760	7210	170	110
Nd	240		1020	3580	56	
Ce/La	2.4	2.3	1.8	3.1	2.7	2.1
Ce/Nd	3.2		4.7	2.0	3.0	

cd = dolomite carbonatite, cc = calcite carbonatite, re1 = rare-earth carbonatite dyke (north ridge), re2 = rare-earth carbonatite dyke (northwest ridge), sy1 = "syenite", sy2 = "syenite".

Analyses cc and sy2 by Cominco Ltd.

arfvedsonite and quartz-bearing syenite. Alkali metasomatism resulted in extensive overgrowth of fine-grained acicular aegirine and prismatic arfvedsonite and replacement of primary igneous textures by metamorphic textures.

Rounded orthoquartzite xenoliths and minor microsyenite xenoliths occur in various parts of the ring structure and may be more abundant locally (*see* Pell, 1986a). Xenoliths commonly show absorption features and reaction rims.

CONTACT AUREOLE

White mica and potassium feldspar are the only common metamorphic minerals observed in impure marbles, marls and silts. Talc and calc-silicates appear to be absent.

Silicification and growth of richteritic amphibole is observed within 10 to 40 centimetres of the contact. There is no mineralogical evidence for major mass transfer within the contact aureole. Trace element abundancies (Nb, REE, Th, F) and radioactivity can however be correlated with the apparent intensity of alteration. The fluid phase responsible for the formation of the contact aureole was probably highly volatile (CO_2, H_2O, F) and did not affect major element concentrations significantly.

GEOCHEMISTRY

Dolomite carbonatite is very low in silica, alumina and alkalies but high in phosphorus (Table 4-5-5). It is enriched in the incompatible elements thorium, uranium, niobium, tantalum, zirconium and light rare-earth elements but is low in titanium, rubidium, potassium and lead. Dolomite carbonatite is relatively depleted in heavy rare-earth elements and the siderophile and chalcophile metals.

Average calcite carbonatite is higher in silica, phosphorus and sodium than dolomite carbonatite. The trace geochemistry is similar to dolomite carbonatite.

Barium, strontium and total rare-earth elements may reach major element concentrations in the rare-earth-rich carbonatite dykes. The dykes may represent residual, low-temperature liquids derived from a dolomite carbonatite-like parental melt.

The metasomatically altered syenite has variable major element concentrations. Its trace element geochemistry is of "diluted" carbonatite character.

STABLE ISOTOPE RATIOS

Samples of calcite, dolomite and ankerite (mostly single crystals) from calcite carbonatite, dolomite carbonatite and a rare-earth carbonatite dyke respectively, were analysed for oxygen and carbon isotope ratios (Figure 4-5-2). All the ^{13}C ratios show values typical of primary igneous carbonatites of mantle origin (Taylor *et al.*, 1967; Pineau *et al.*, 1973). The ^{18}O values are variable, a feature commonly observed in carbonate minerals. An elevated ^{18}O signature, in comparison with mantle values, is usually taken to be indicative of postmagmatic recrystallization and deuteric alteration (Taylor *et al.*, 1967). Both processes preferentially affect carbonate minerals (rather than silicates) and oxygen isotope ratios rather than carbon isotope ratios. The extremely fresh samples of calcite carbonatite from drill cores are not affected at all by alteration. Dol-

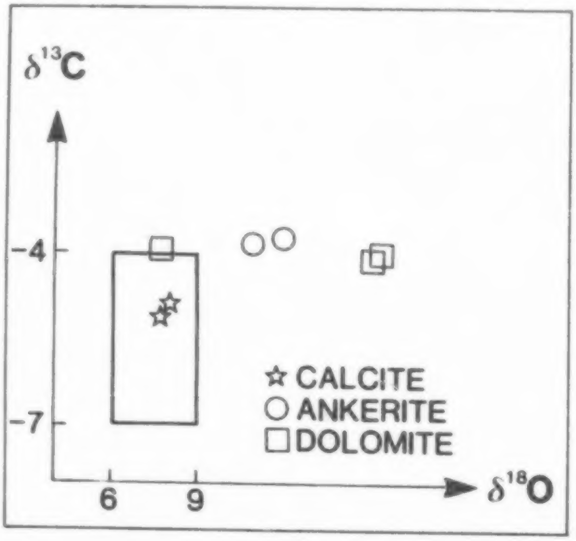

Figure 4-5-2. Stable isotope diagram of selected carbonate minerals (analyses by Dr. K. Muehlenbachs, University of Alberta, Edmonton, Alberta). $\delta^{13}C$ ratios normalized to per mill PDB, $\delta^{18}O$ ratios normalized to per mill SMOW. Box outlines the range of primary igneous carbonatites unaffected by weathering or dueteric and hydrothermal alteration (Taylor *et al.*, 1967).

omite, carbonatite, almost always with a brownish tint due to weathering, shows ^{18}O values typical of mantle origin and elevated ^{18}O values due to recrystallization and deuteric alteration. Ankerite from carbonatite dykes rich in rare-earths shows somewhat elevated ^{18}O signatures, but ^{13}C values of mantle character.

DISCUSSION

The Aley is one of the best exposed and preserved alkaline-carbonatite complexes in the world. Besides its niobium potential the complex provides insight into problems of alkaline-carbonatite rock genesis: mode of emplacement, diversification of alkaline magmas, nature of the mantle source, processes in the mantle source region and metallogenesis.

ACKNOWLEDGMENTS

Cominco Ltd. provided a 1:5000 geological map based on four man-months of work completed during 1983 and 1984, as well as generous financial and logistical support. Valuable discussions with H.J. Greenwood (The University of British Columbia), K.R. Pride and P.C. LeCouteur (Cominco Ltd.) contributed much to the fieldwork and research. Support by the Canada/British Columbia Mineral Development Agreement for current research is fully acknowledged.

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PHOSPHATE INVENTORY*
(82G and J)

By S. B. Butrenchuk

INTRODUCTION

During the summer of 1986 the author began an investigation of phosphate deposits in southeastern British Columbia. Fieldwork consisted of examining approximately 80 phosphate localities in the area bounded by the Alberta-British Columbia boundary on the east, Fernie on the west, Kananaskis Lakes on the north and the Canada-United States border on the south. Samples were collected from 59 localities (Figure 4-6-1). Individual phosphate beds were chip sampled in intervals of 1 metre or less and strata above and below the phosphate were also sampled. Where outcrop was insufficient to permit chip sampling, grab samples of the phosphate were taken. Specimens were obtained from most localities for petrographic work and whole rock analyses. Stratigraphic sections were measured where there was sufficient exposure of the phosphate and enclosing strata.

Samples collected in the field are being analysed for phosphate copper, lead, zinc and arsenic at the Ministry of Energy, Mines and Petroleum Resources laboratory facilities in Victoria using X-ray fluorescent techniques and for phosphate using wet chemical techniques. In addition these samples will be analysed for uranium, vanadium and a number of rare earth elements.

REGIONAL GEOLOGY

Phosphate deposits in southeastern British Columbia occur in a sequence of marine strata ranging in age from Devonian to Jurassic (Figure 4-6-2). These strata lie within the thrust and fold belt of the Rocky Mountains and have generally been thrust eastward onto the craton. They have a complex depositional history that is recorded by a number of unconformities. Older strata in the sequence are primarily platformal carbonates of Devonian-Mississippian age, conspicuous by the their resistant cliff-forming appearance. During the Pennsylvanian-Permian, deposition of shallow marine fine clastic and carbonate strata took place under quiescent conditions (Douglas *et al.*, 1970). In this time period there were a number of marine transgressions and regressions. Triassic sediments are postulated to have been laid down during minor marine transgressions and regressions in a deltaic environment (Douglas *et al.*, 1970). A regional unconformity marks the contact between the Triassic and Jurassic. Jurassic shales were deposited in a moderately deep marine environment. Sedimentation gradually became nonmarine at the end of the Jurassic. The phosphate-bearing sequence is overlain by nonmarine Cretaceous strata that are host to extensive coal measures.

The geological structure of southeastern British Columbia is characterized by a number of southwest-dipping thrust faults that have displacements of up to 165 kilometres (MacDonald, 1985; Benvenuto and Price, 1979). These thrusts extend for many kilometres in a north-south direction. Folding in the area can be related to thrust faulting and stratigraphic sequences are often overturned. Much of the deformation has been absorbed by the Fernie Formation. Areas where phosphate beds have been thickened by repetitive thrust faulting are of particular significance.

STRATIGRAPHY: PHOSPHATIC UNITS

EXSHAW FORMATION

Exposures of Exshaw Formation are restricted to a narrow band in the Highrock Ranges north and south of Crowsnest Pass and locally southwest of Fernie. This is a distinctive, black shale unit that forms an excellent marker. Strata include black, thin-bedded to massive shale, limestone, phosphatic shale and phosphate. The thickness of this unit varies from 6 metres to 30 metres (Christie and Kenny, 1984).

Phosphate occurs at four horizons within the Exshaw Formation (MacDonald, 1985). A basal phosphate unit is present in sandstone overlying the top of the Palliser Formation. Three other phosphate horizons occur within the Exshaw section. They consist of pelletal and nodular phosphate and a fine-grained phosphorite and are best developed in the region north of the Crowsnest Pass (MacDonald, 1985; Kenny, 1977). Much of this section is located along the Alberta-British Columbia boundary or in Alberta.

ISHBEL GROUP

The Ishbel Group is comprised of four formations containing a number of phosphatic horizons. Phosphate is present in the Johnson Canyon, Ross Creek and Ranger Canyon Formations. The Telford Formation is nonphosphatic except for phosphate laminae and rarely a very thin phosphate bed.

This sequence of strata, consisting of fine-grained siltstone and sandstone, chert, carbonate and minor shale (McGugan and Rapson, 1962, 1964) increases in thickness from east to west. It is best developed in the Telford thrust plate where all four formations are present. Elsewhere only the Johnson Canyon and/or Ranger Canyon Formations are present.

JOHNSON CANYON FORMATION

The Johnson Canyon Formation, which unconformably overlies Kananaskis or Tunnel Mountain strata, consists of a series of thin to medium-bedded siltstones and sandstones with minor shale and chert. A phosphatic chert pebble conglomerate, a few centimetres thick, marks its base (MacRae and McGugan, 1977). Phosphate is present as black ovoid nodules or distinct horizons within sandstone or siltstone beds (Plate 4-6-1) as phosphate-cemented sandstone or in pelletal form. Phosphatic intervals range in thickness from less than 1 metre to a maximum of 22 metres in the Mount Broadwood area (Figure 4-6-3).

TELFORD FORMATION

The Telford Formation comprises a thick sequence of carbonates and sandy carbonates. These strata are resistant cliff-forming units that are preserved only in the Telford thrust plate (MacRae and McGugan, 1977). Phosphate is absent in the Telford Formation except for a few phosphatic laminae and a single phosphatic coquinoid bed (Plates 4-6-2 and 4-6-3).

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

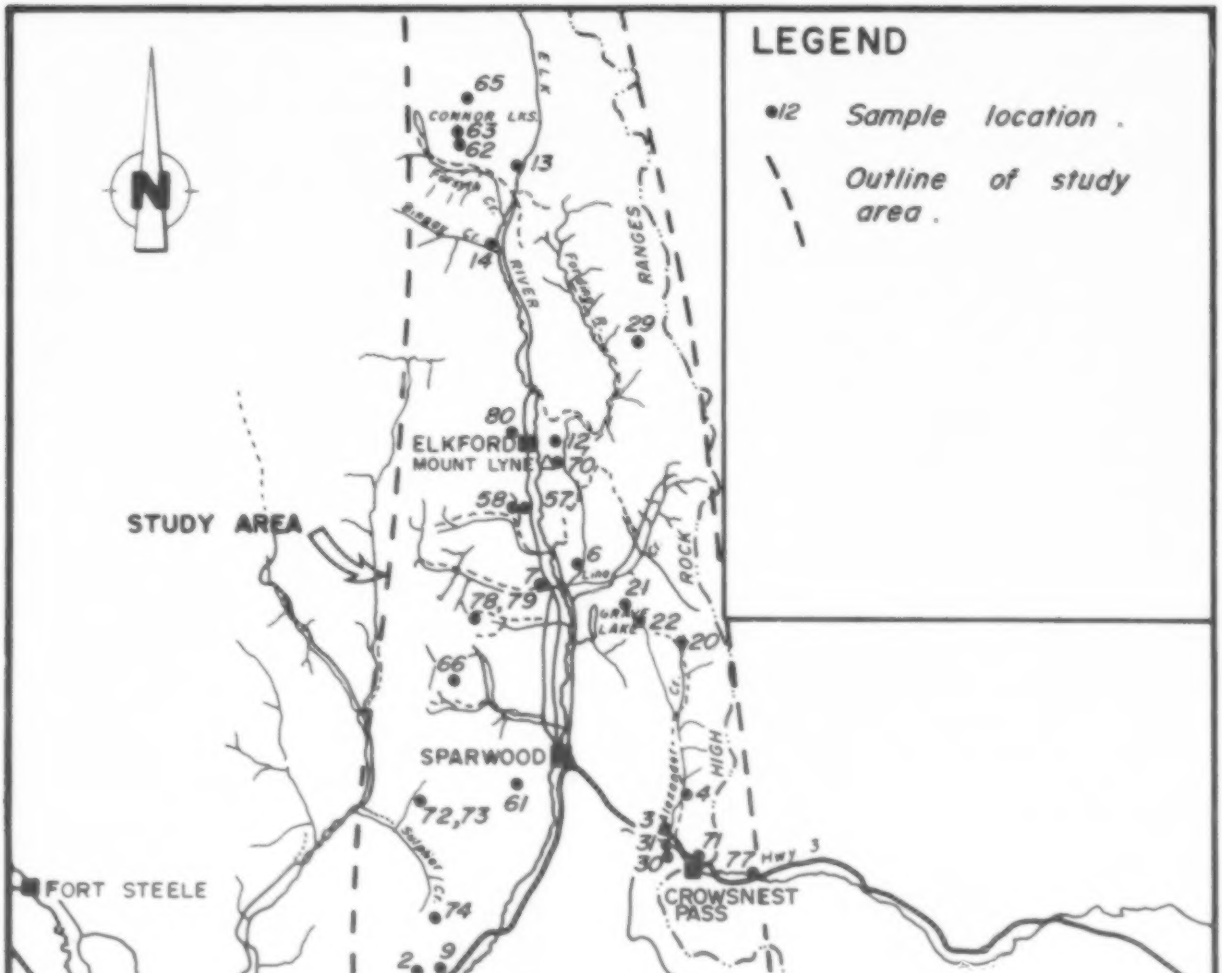
LEGEND
●12 Sample location.
Outline of study area.
N
STUDY AREA
ELK RIVER
CONNOR LKS.
Forsyth Cr.
Bingay Cr.
Fording R.
RANGES
ROCK
HIGH
ELKFORD
MOUNT LYNE
SPARWOOD
GRAVE LAKE
Line
Sulphur Cr.
Michel Cr.
FORT STEELE
FERNIE
CROWSNEST PASS
Hwy 3
Hwy 93
MOUNT BROADWOOD
Cabin
ALBERTA
U.S.A.
0
20
Km
65
63
62
13
14
29
80
12
70
58
57
6
7
78,79
21
22
20
66
72,73
61
4
3
31
30
71
77
74
2
9
1
11
10
8
36
37
76
24
17
86
15
50
85
83,84
42
40
41
48
52
38
53
27
43
47
54
28,44

Figure 4-6-1. Sample location map.

Age	Group/ Formation (Thickness, Metres)		Lithology	Phosphate
Cretaceous	Kootenay Fm.		• grey to black carbonaceous siltstone and sandstone; nonmarine; coal	
Jurassic	Fernie Fm. (± 244)		• black, shale, siltstone, limestone; marine to nonmarine at top • glauconitic shale in upper section • belemnites common fossil • rare calcareous sandstone • thin conglomerate may be present at base	• basal phosphate in Sinemurian strata; general pelletal/oolitic; rarely nodular; 1 to 2 metres thick; locally two phosphate horizons; top of phosphate may be marked by a yellowish-orange-weathering marker bed • approximately 60 metres above base — low-grade phosphate-bearing calcareous sandstone horizon or phosphatic shale
Triassic	Spray River Group	Whitehorse Fm.	• dolomite, limestone, siltstone	
		Sulphur Mountain Fm. (100-496)	• grey to rusty brown-weathering sequence of siltstone, calcareous siltstone and sandstone, shale, silty dolomite and limestone	• nonphosphatic in southeastern British Columbia
Permian	Ishbel Group	Ranger Canyon Fm. (1-60)	• sequence of chert, sandstone and siltstone; minor dolomite and gypsum; conglomerate at base • shallow marine deposition	• basal conglomerate-chert with phosphate pebbles present (≤1 metre) • upper portion — brown, nodular phosphatic sandstone; also rare pelletal phosphatic sandstone (few centimetres to + 4 metres)
		Ross Creek Fm. (90-150)	• sequence of siltstone, shale, chert, carbonate and phosphatic horizons areally restricted to Telford thrust sheet • west of Elk River, shallow marine deposition	• phosphate in a number of horizons as nodules and finely disseminated granules within the matrix • phosphatic coquinoid horizons present
		Telford Fm. (210-225)	• sequence of sandy carbonate containing abundant brachiopod fauna; minor sandstone • shallow marine deposition	• rare, very thin beds or laminae of phosphate; rare phosphatized horizon
		Johnson Canyon Fm. (1-60)	• thinly bedded, rythmic sequence of siltstone, chert, shale, sandstone and minor carbonate; basal conglomerate • shallow marine deposition	• basal conglomerate (maximum 30 centimetres thick) contains chert and phosphate pebbles • phosphate generally present as black ovoid nodules in light-coloured siltstone; phosphatic interval ranges in thickness from 1 to 22 metres • locally present as a black phosphatic siltstone
Pennsylvanian	Kananaskis Fm. (± 55)		• dolomite, silty, commonly contains chert nodules or beds	
Mississippian	Rundle Group (± 700)		• limestone, dolomite; minor shale, sandstone and cherty limestone	
Mississippian	Banff Fm. (280-430)		• shale, dolomite, limestone	
Devonian-Mississippian	Exshaw Fm. (6-30)		• black shale, limestone • areally restricted in southeastern British Columbia	• basal phosphate less than 1 metre thick; pelletal • phosphatic shale and pelletal phosphate 2 to 3 metres above base • an upper nodular horizon
Devonian	Palliser Fm.		• limestone	

Figure 4-6-2. Stratigraphy of phosphate-bearing formations in southeastern British Columbia.

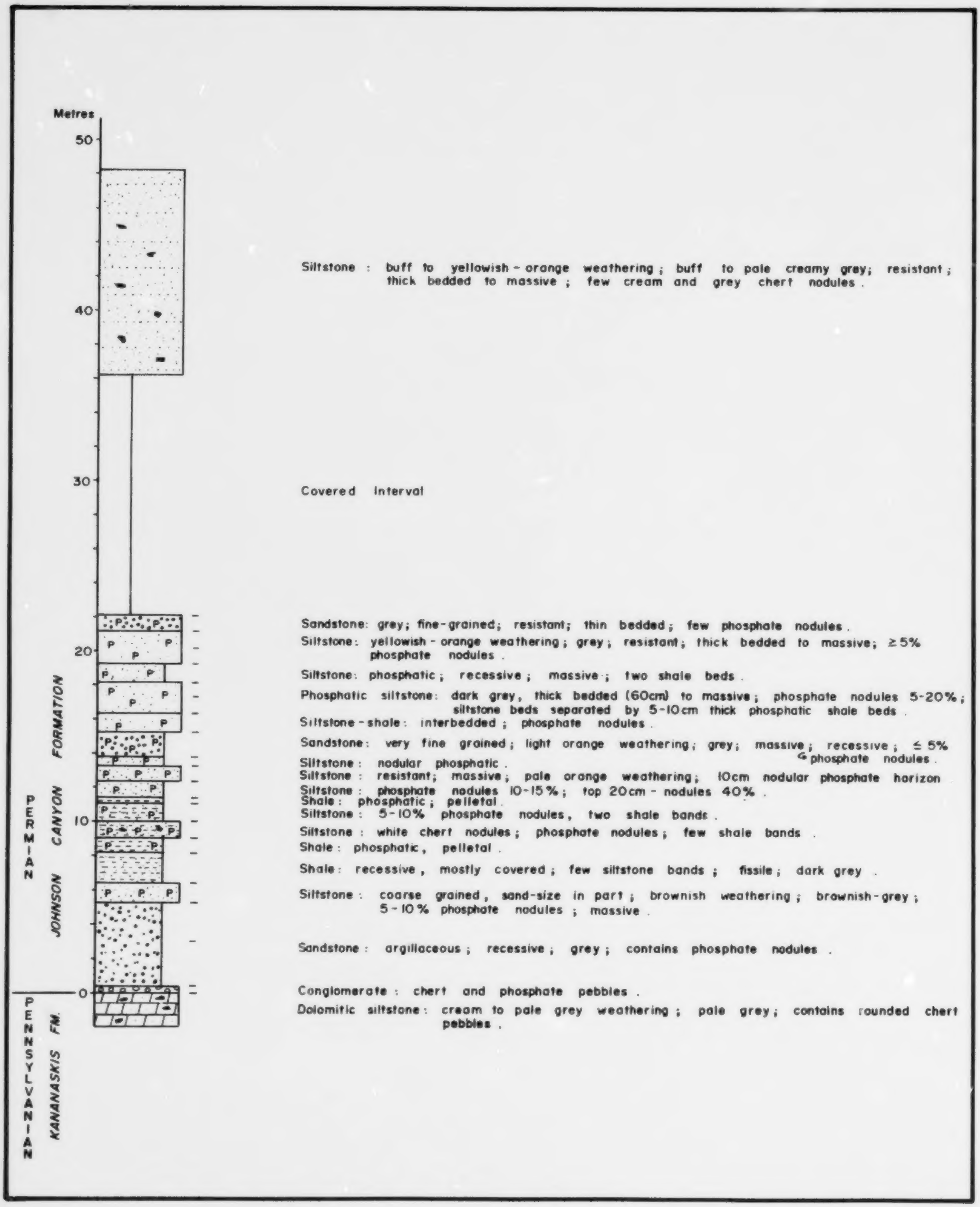
Metres
50
40
30
20
10
0
PERMIAN
JOHNSON CANYON FORMATION
PENNSYLVANIAN
KANANASKIS FM.
Siltstone : buff to yellowish - orange weathering ; buff to pale creamy grey; resistant ; thick bedded to massive ; few cream and grey chert nodules .
Covered Interval
Sandstone: grey; fine-grained; resistant; thin bedded; few phosphate nodules .
Siltstone: yellowish - orange weathering; grey; resistant; thick bedded to massive; ≥5% phosphate nodules .
Siltstone: phosphatic; recessive; massive; two shale beds .
Phosphatic siltstone: dark grey, thick bedded (60cm) to massive; phosphate nodules 5-20%; siltstone beds separated by 5-10cm thick phosphatic shale beds .
Siltstone - shale: interbedded; phosphate nodules .
Sandstone: very fine grained; light orange weathering; grey; massive; recessive; ≤ 5% phosphate nodules .
Siltstone : nodular phosphatic .
Siltstone : resistant; massive; pale orange weathering; 10cm nodular phosphate horizon
Siltstone : phosphate nodules 10-15%; top 20cm - nodules 40% .
Shale : phosphatic; pelletal .
Siltstone : 5-10% phosphate nodules, two shale bands .
Siltstone : white chert nodules; phosphate nodules; few shale bands .
Shale : phosphatic, pelletal .
Shale: recessive, mostly covered; few siltstone bands; fissile; dark grey .
Siltstone : coarse grained, sand-size in part; brownish weathering; brownish-grey; 5-10% phosphate nodules; massive .
Sandstone : argillaceous; recessive; grey; contains phosphate nodules .
Conglomerate : chert and phosphate pebbles .
Dolomitic siltstone : cream to pale grey weathering; pale grey; contains rounded chert pebbles .

Figure 4-6-3. Stratigraphic Section 17, Mount Broadwood.

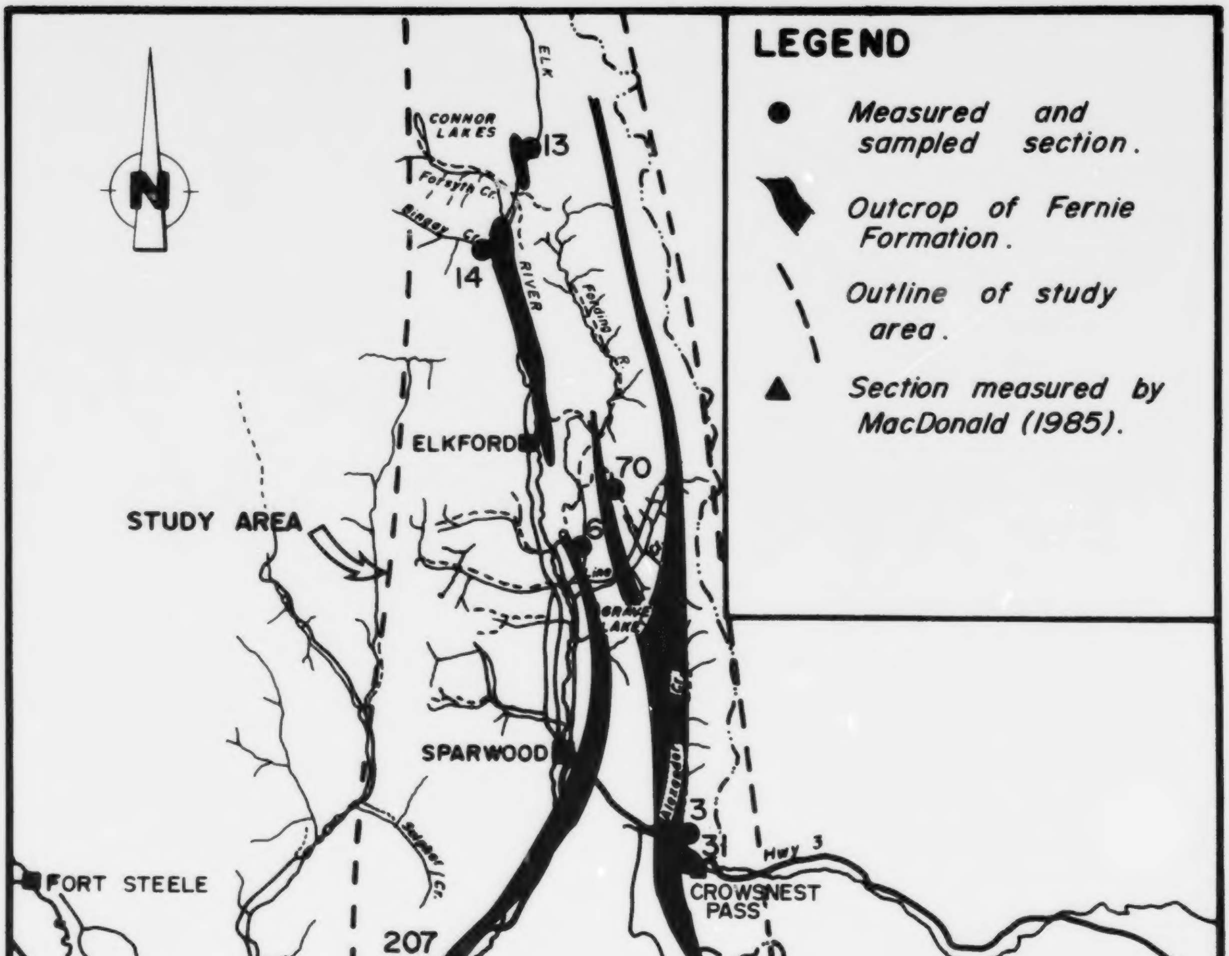
LEGEND
● Measured and sampled section.
Outcrop of Fernie Formation.
Outline of study area.
▲ Section measured by MacDonald (1985).
N
ELK
CONNOR LAKES
13
Forsyth Cr.
Bingay Cr.
14
RIVER
Fording R.
ELKFORD
70
STUDY AREA
6
GRAVE LAKE
SPARWOOD
3
31
Hwy 3
CROWSNEST PASS
FORT STEELE
Sulphur Cr.
207
FERNIE
ALBERTA
Hwy 3
220
MOUNT BROADWOOD
Bighorn Cr.
38
Cabin Cr.
Hwy 93
0
20
Km
U.S.A.

Figure 4-6-4. Distribution of the Jurassic Fernie Formation in southeastern British Columbia.

ROSS CREEK FORMATION

The Ross Creek Formation, preserved only in the Telford thrust plate, consists of a sequence of recessive thin-bedded siltstone, argillaceous siltstone, minor carbonate and chert (MacRae and McGugan, 1977), Pelletal and nodular phosphate layers occur in the upper portion together with relatively thin coquinoid horizons that contain phosphate nodules (Plate 4-6-4).

RANGER CANYON FORMATION

The Ranger Canyon Formation unconformably overlies the Ross Creek Formation and consists of resistant cliff-forming chert, cherty sandstone and siltstone. Minor gypsum and dolomite are also present (MacRae and McGugan, 1977).

The base is marked by a phosphate-cemented chert-pebble conglomerate that also contains massive phosphate intraclasts, nodules and pebbles. This conglomerate is well exposed in the Cabin Creek area (Plate 4-6-5). Phosphate also occurs in a brown sandstone in the upper part of the formation. It is typically nodular with nodules ranging in size from 1 to 6 centimetres. Phosphatic horizons range in thickness from a few centimetres at Mutz Creek to 4 metres at Fairy Creek, north of Fernie. Phosphate is also present as phosphatic chert, in pelletal form or as the matrix in fine-grained sandstones or siltstones (Plate 4-6-6).

SPRAY RIVER GROUP

There are no known phosphate deposits in the Triassic Spray River Group in southeastern British Columbia, although Telfer (1933, page 599) does report some samples assaying up to 6 per cent P_2O_5 in Triassic shales.

The Whitehorse Formation is present in the area north of Elkford, but is very thin; elsewhere in the region the Spray River Group contains only strata of the Sulphur Mountain Formation. Although they contain no phosphate, they do provide a useful marker sequence as phosphate occurs in the stratigraphic interval immediately above and below.

FERNIE FORMATION

Triassic strata are unconformably overlain by dark grey to black shales, minor limestone, siltstone and sandstone of the Jurassic Fernie Formation (Freebold, 1957, 1969). This formation thickens from east to west. A persistent phosphorite bed 1 to 2 metres thick occurs at the base of the Fernie in strata of Sinemurian age (Plate 4-6-7). It is typically black and pelletal; phosphate nodules and bioclastic debris are occasionally present. Limonitic blebs, interpreted to represent oxidized pyrite grains, are common. Generally this phosphate rests directly on strata of Triassic age, with a thin conglomerate (+ 5 centimetres) at its base. The phosphate interval may be present as two phosphorite beds separated by phosphatic shale. Thicknesses in excess of 2 metres are attained locally, as at Mount Lyne where 4 metres of phosphatic rock are present (Plate 4-6-8). The top of the phosphate may be marked by a yellowish-orange calcareous marker bed 2 to 5 centimetres thick.

A second phosphate horizon lies approximately 60 metres above the base of the Fernie. It is low grade and may be associated with a belemnite-bearing calcareous sandstone horizon. This upper horizon was only observed on the railroad tracks south of the Highway 3 roadcut at Alexander Creek and in a poorly exposed outcrop north of Mount Lyne, where it occurs in shale rather than sandstone.

PHOSPHATE DEPOSITS

Early this century Telfer (1933), while working for The Consolidated Mining and Smelting Company of Canada, Limited (Cominco Ltd.), recognized a number of distinct stratigraphic intervals containing phosphate. Since this early work a number of authors have recorded the presence of phosphate in southeastern British Columbia. MacDonald (1985), in the course of his study of phosphate deposits in Alberta, also completed a cursory evaluation of the phosphate potential of southeastern British Columbia and a number of companies have explored for phosphate in the region. However, there has been no broad assessment of these data. This study attempts to synthesize the data, determine the most favourable stratigraphic intervals for phosphate and evaluate the economic potential of the various phosphate deposits. It makes it clear that in southeastern British Columbia only the Jurassic Fernie Formation and the Permian Ishbel Group contain phosphate deposits of some significance.

FERNIE FORMATION

The Fernie Formation occupies a broad syncline known as the Fernie basin. This structure is canoe-shaped and covers an area that extends 100 kilometres in a north-south direction and has an average width of approximately 20 kilometres. Pelletal phosphorite and phosphatic shale occur at the base of the formation in strata that unconformably overlie the Triassic Sulphur Mountain Formation. This contact can be traced for approximately 310 kilometres (Figure 4-6-4) although it is not everywhere exposed.

During Sinemurian time there was a rapid marine transgression. Phosphate was deposited as a single bed, or as two beds separated by phosphatic shale, during a period of very slow clastic sedimentation. This phosphatic unit extends throughout the basin and is consistently 1 to 2 metres thick (Figure 4-6-5). We estimate that 8.4 billion tonnes of phosphatic rock may have been deposited, but less than 5 per cent of this can be considered as a potential resource. The resource potential is estimated to be 400 million tonnes with a phosphate content of 15 to 25 per cent P_2O_5. A downdip extension of 300 metres has been used in the above calculation to represent a practical mining depth.

Surface exposures are invariably weathered and may be enriched in phosphate as a result of the leaching of carbonates. The presence of blebs of limonite replacing pyrite grains provides evidence of oxidation, but thin-section studies indicate that weathering has not affected the phosphate pellets. As we were only able to sample surface exposures we could not determine the depth to which the phosphate has been weathered or how much the grade has been affected.

The southernmost exposures of the basal phosphate of the Fernie Formation occur in the Cabin Creek area. Exploration by First Nuclear Corp. Ltd. (Hartley, 1982), Imperial Oil Ltd. (Van Fraassen, 1978) and the author has demonstrated that a phosphate bed averaging 1.5 metres in thickness occurs along a strike length of 27 kilometres. Phosphate is present in a broad synclinal structure modified by a number of thrust faults and smaller folds. Thrust faulting has thickened the phosphate bed at some localities. Elsewhere, the phosphate has been remobilized into the axial portions of folds (Hartley, 1982). Phosphate content is in the range of 13 to 20 per cent P_2O_5. Less silty varieties contain better than 20 per cent P_2O_5 (Hartley, 1982).

North of Crowsnest, at the Crow mine, a phosphate bed 1.5 metres thick has been thickened by repetitive thrust faulting (Telfer, 1933). Individual phosphate beds are thrust one upon another at some localities and faulted out at others along strike. Our work in this area was confined to the examination of one trench and a small surface exposure. The phosphate beds are repeated four times in the trench, increasing the width of the phosphate section to 16 metres. The phosphate content of these beds averages 26 per cent P_2O_5.

In the west Line Creek area the basal phosphate horizon can be traced for a strike length of 15 kilometres. The strata dip 40 to 75 degrees easterly. The phosphate bed varies in thickness from less than 1 metre south of Line Creek, to in excess of 3 metres at Mount

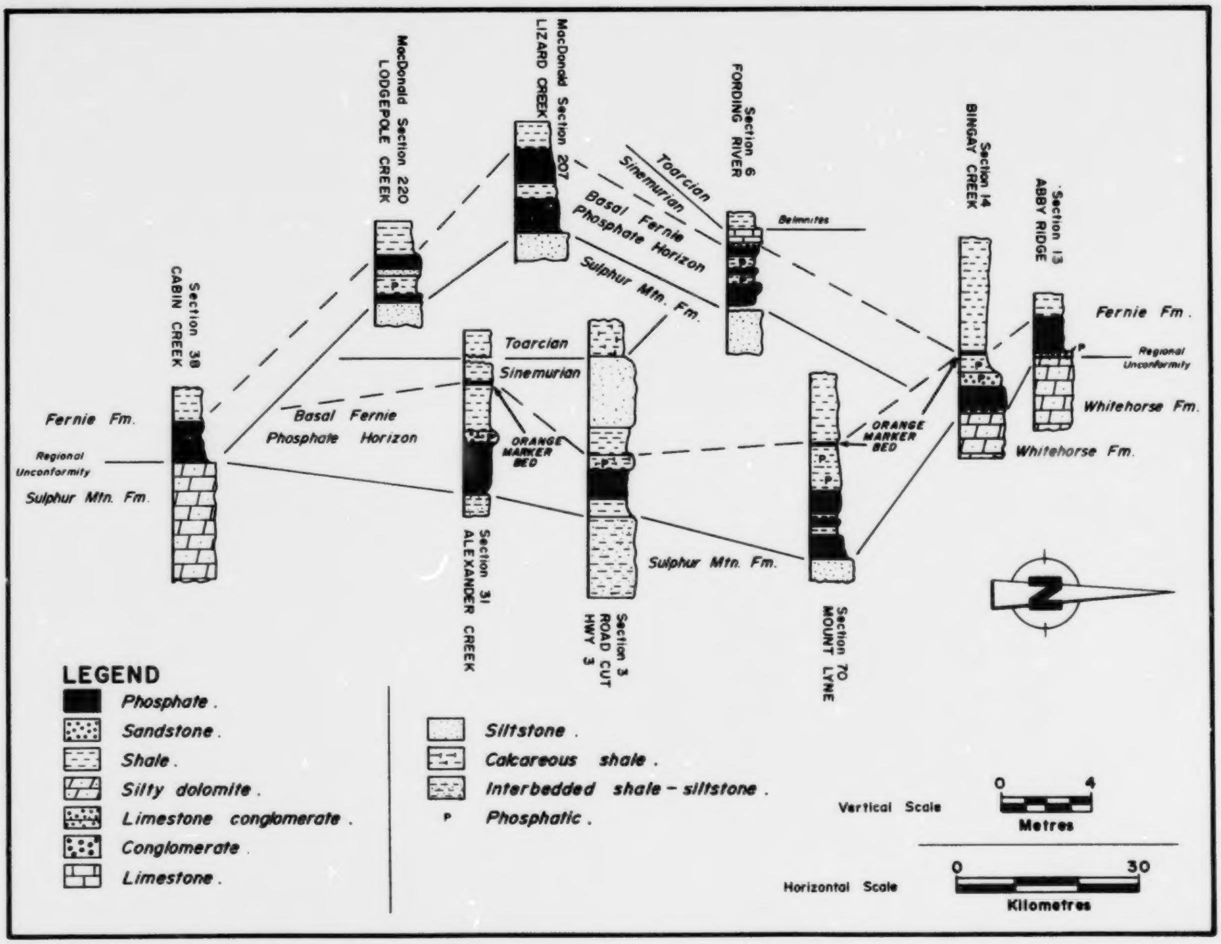
Section 38 CABIN CREEK
MacDonald Section 220 LODGEPOLE CREEK
MacDonald Section 207 LIZARD CREEK
Section 6 FORDING RIVER
Section 14 BINGAY CREEK
Section 13 ABBY RIDGE
Section 31 ALEXANDER CREEK
Section 3 ROAD CUT HWY 3
Section 70 MOUNT LYNE
Fernie Fm.
Regional Unconformity
Sulphur Mtn. Fm.
Basal Fernie Phosphate Horizon
Toarcian
Sinemurian
Orange Marker Bed
Belemnites
Whitehorse Fm.
LEGEND
Phosphate.
Sandstone.
Shale.
Silty dolomite.
Limestone conglomerate.
Conglomerate.
Limestone.
Siltstone.
Calcareous shale.
Interbedded shale – siltstone.
P Phosphatic.
Vertical Scale
0
4
Metres
Horizontal Scale
0
30
Kilometres
N

Figure 4-6-5. Stratigraphic correlation of the basal Fernie phosphate in southeastern British Columbia.

Lyne. Phosphate content ranges from a low of 3.7 per cent P_2O_5 in a diamond-drill hole (Hannah, 1980) to a high of 23.7 per cent P_2O_5 across 1.6 metres in a back-hoe trench (Hannah, 1980).

ISHBEL GROUP

Pennsylvanian-Permian strata occur extensively throughout southeastern British Columbia (Figure 4-6-6) but exposures of the Permian Ishbel Group are restricted to a narrow stratigraphic interval. The best development of the Ishbel Group is in the Telford thrust plate west of the Elk River and north of Sparwood (MacRae and McGugan, 1977). The Ishbel Group has been correlated with the Phosporia Formation of the western United States which contains extensive phosphate deposits

The Permian phosphate deposits in southeastern British Columbia occur at several stratigraphic intervals; most important appear to be the Johnson Canyon and the Ranger Canyon Formations. Phosphate is also present in the Ross Creek Formation but its distribution is restricted and exposures are rare. Deposition of the phosphate appears to have taken place in a shallow shelf environment with the eastern sequence being deposited close to a hingeline parallel to a shoreline trend (MacRae and McGugan, 1977). Host lithologies vary from conglomerate to fine-grained sandstone, siltstone and shale. Phosphatic intervals vary considerably in thickness and grade.

Phosphate occurs in a number of forms but nodular varieties are the most common. Phosphate nodules may comprise anywhere from 5 per cent of the rock by volume to almost the entire rock and contain up to 32 per cent P_2O_5 (Telfer, 1933). The best exposures of this nodular variety occur in an outcrop of Johnson Canyon Formation near Mount Broadwood and in the Ranger Canyon Formation north of Forsyth Creek, in the Connor Lakes area.

Several exposures of the Johnson Canyon Formation were examined in the Bighorn-Cabin Creek area at the southeastern limit of Permian strata. Phosphate is commonly present as subrounded nodules 1 to 2 centimetres in diameter in the lower part of the formation. Phosphatic intervals vary considerably, ranging in thickness from less than 5 metres in the southeast to 22 metres at Mount Broadwood (Figure 4-6-7). Phosphate content is exceedingly low, averaging less than 2 per cent P_2O_5 across widths of 1 metre. Northwesterly along the same trend, in the vicinity of the Fernie ski hill, phosphatic intervals are 1 metre thick or less. In two of the three sections measured a basal conglomerate 25 to 30 centimetres thick contains chert and phosphate pebbles and has a phosphate content averaging 3.9 per cent P_2O_5. In the area of the Fernie ski hill this conglomerate is only 2 centimetres thick.

North of Forsyth Creek, in the Connor Lakes area, several exposures of phosphate are present in the Ranger Canyon Formation. In this area a resistant chert horizon is overlain by a sandstone bed

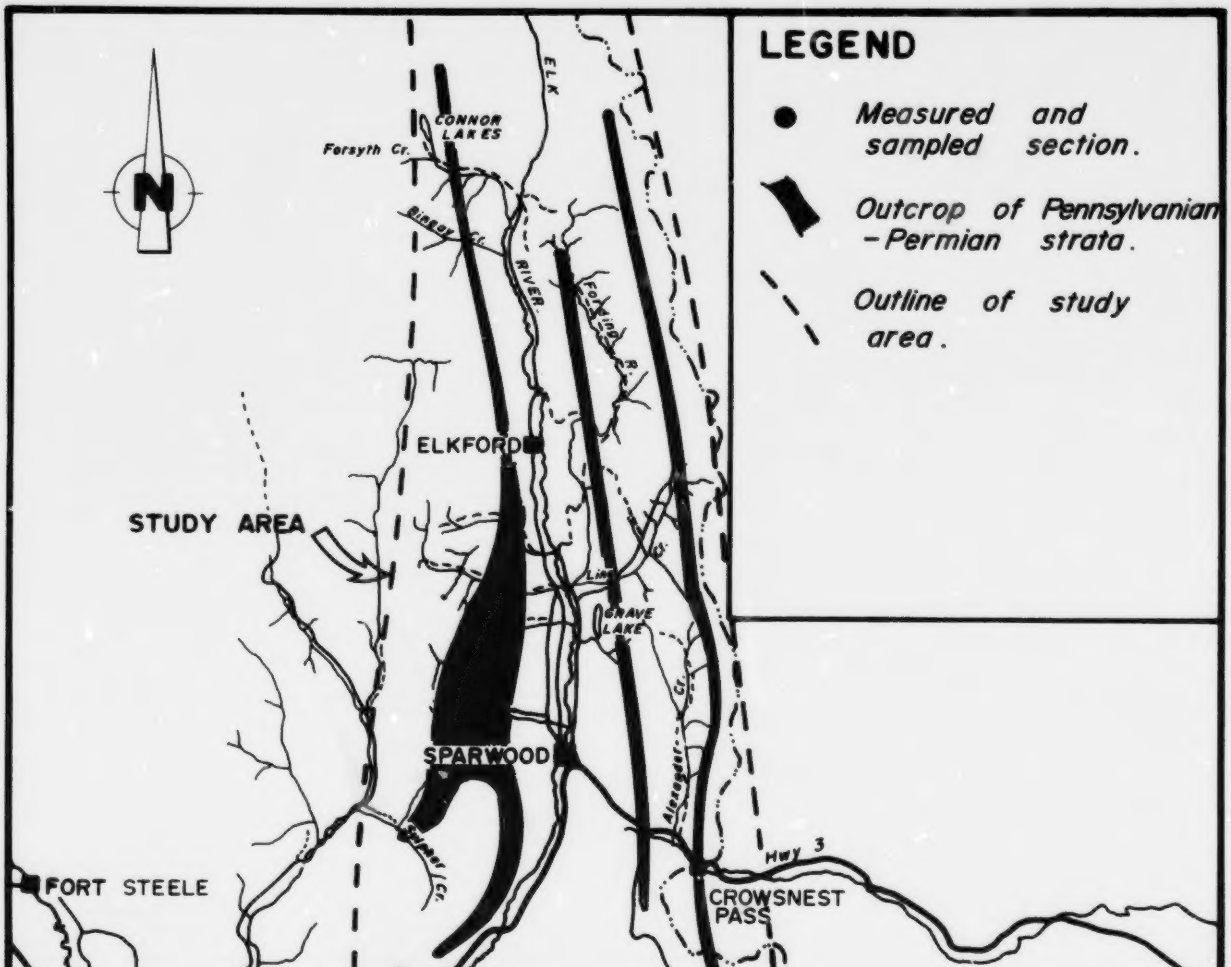
LEGEND
● Measured and sampled section.
Outcrop of Pennsylvanian -Permian strata.
Outline of study area.
N
CONNOR LAKES
Forsyth Cr.
Bingay Cr.
ELK RIVER
Fording R.
ELKFORD
STUDY AREA
Line Cr.
GRAVE LAKE
Alexander Cr.
SPARWOOD
Cr.
Hwy 3
FORT STEELE
CROWSNEST PASS
8
FERNIE
ALBERTA
17
MOUNT BROADWOOD
Bighorn
84
41
Cabin Cr.
Hwy 93
0
20
Km
U.S.A.

Figure 4-6-6. Distribution of Pennsylvanian-Permian strata in southeastern British Columbia.

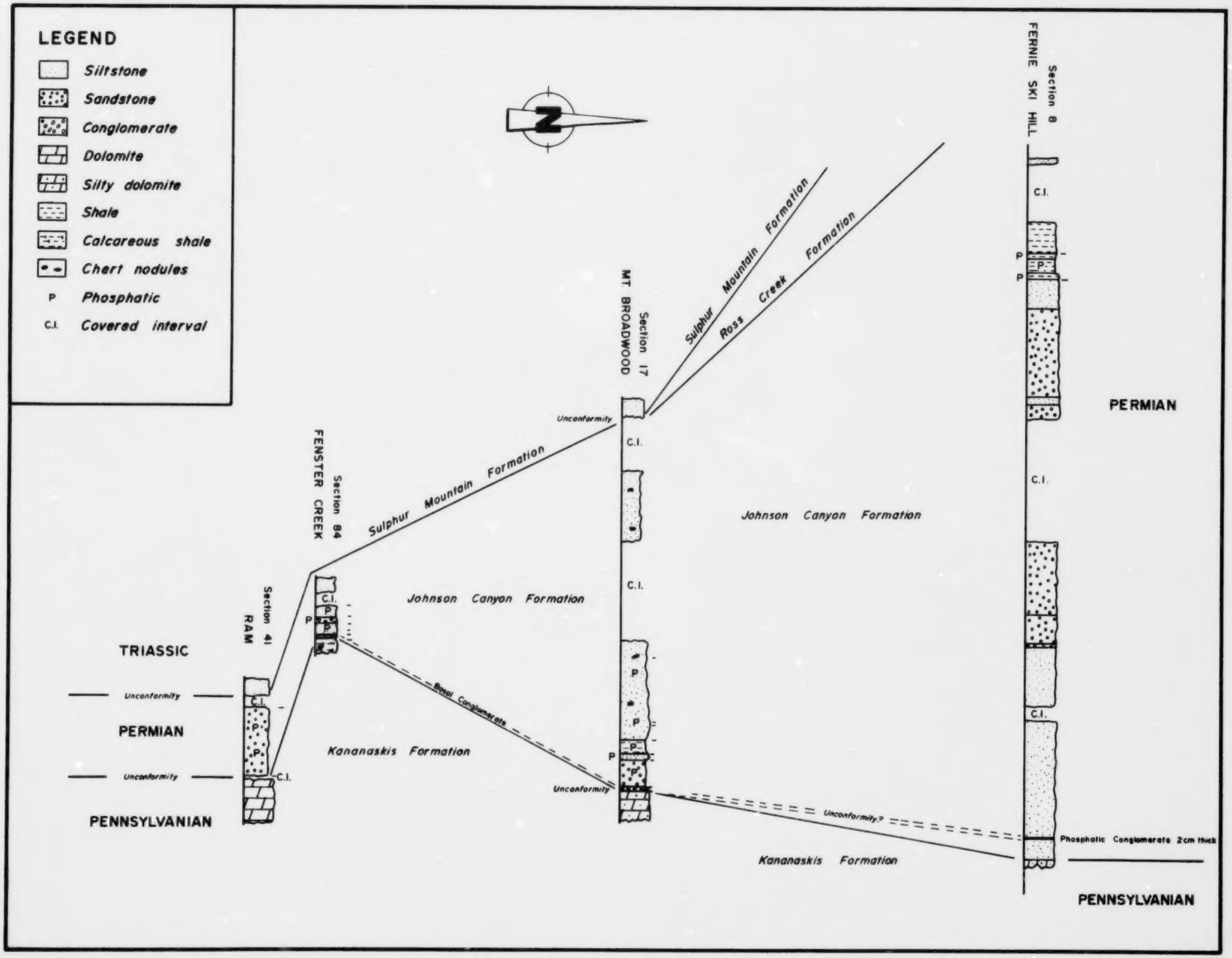
LEGEND
Siltstone
Sandstone
Conglomerate
Dolomite
Silty dolomite
Shale
Calcareous shale
Chert nodules
P Phosphatic
C.I. Covered interval
N
Section 8
FERNIE SKI HILL
Section 17
MT. BROADWOOD
Section 84
FENSTER CREEK
Section 41
RAM
Sulphur Mountain Formation
Ross Creek Formation
Johnson Canyon Formation
Kananaskis Formation
Unconformity
Unconformity?
Basal Conglomerate
Phosphatic Conglomerate 2cm thick
C.I.
P
TRIASSIC
PERMIAN
PENNSYLVANIAN

Figure 4-6-7. Stratigraphic correlation of phosphate-bearing strata, Johnson Canyon Formation, Fernie-Cabin Creek area.

1 metre thick containing 10 to 15 per cent phosphate nodules by volume. The nodules are black, subrounded, and average 5 centimetres in diameter. They contain 23 to 28 per cent P_2O_5 but samples of the sandstone assayed only 1.6 percent P_2O_5. The geology of this area is complicated by a number of steeply dipping normal faults which have caused a thickening of the section; fault repetitions can be seen in outcrop, especially in the beds below the chert horizon. At one locality we were able to measure a phosphatic interval of 10 metres below the chert horizon. Throughout this section the phosphate content was generally less than 5 per cent P_2O_5 except for a bed 50 centimetres thick, at the base of the chert, which assayed 16.5 per cent P_2O_5.

On the eastern margin of the study area the Permian section is only a few metres thick. Exposures examined consisted of nodular phosphate in a sandstone matrix. A sample of nodules from an outcrop in the Crowsnest area, north of Highway 3, assayed 24.0 per cent P_2O_5. A sample of sandstone from the same locality had a phosphate content of 12.3 per cent P_2O_5. This phosphate horizon, which is approximately 1 metre thick, can be traced as far south as Flathead Pass and as far north as Todhunter Creek.

DISCUSSION

Phosphate exposures of are not very distinctive. Phosphate beds are generally thin and good exposures are rare. The basal phosphate of the Fernie Formation is typicaly pelletal, dark grey to black and recessive. Permian strata generally contain black ovoid phosphate nodules, although pelletal varieties are also present. Phosphate may also occur as a cement in fine clastic rocks and as cement or pebbles in conglomerates.

Several criteria can be used to recognize phosphate in the field. On weathered surfaces it may exhibit a pale bluish coloration and will give off a distinct bituminous odour when struck by a hammer. Chemical tests are available for qualitative determination of phosphate in the field. A spectrometer is an invaluable tool; phosphatic sections in the Permian give readings in the range of 150 to 400 counts per second compared to a background of less than 100 counts. Readings for the Fernie phosphate are in the range of 500 to 900 counts per second as compared to a background generally less than 200 counts.

The best potential for phosphate in southeastern British Columbia occurs at the base of the Fernie Formation. The phosphate content averages 15 to 25 per cent P_2O_5 across a thickness of 1 to 2 metres. Locally there has been some thickening of the phosphatic unit. At the present time a grade of approximately 30 per cent P_2O_5 is required for processing. Fernie phosphate would therefore require beneficiation. Metallurgical tests to date have been unsatisfactory (Kenny, 1977) but recent metallurgical work in the United States (Rule, *et al.*, 1982 ; Judd, *et al.*, 1986) may offer some encouragement for the future recovery of phosphate from the Fernie Formation.

The phosphate potential of the Ishbel Group is more difficult to assess. Phosphatic intervals at several localities exceed 5 metres in thickness but grades are less than 5 per cent P_2O_5. Most of this phosphate occurs as nodules having phosphate contents in excess of 23 per cent P_2O_5. These nodular varieties may present a potential phosphate resource if an inexpensive method can be found to separate the nodules from the fine clastic matrix.

ACKNOWLEDGMENTS

Funding for this program was provided by the Canada/British Columbia Mineral Development Agreement (MDA). The author gratefully acknowledges Cominco Ltd., Crows Nest Resources Ltd. and Esso Minerals Canada for providing pertinent phosphate data, David Grieve for support throughout the summer, Shaun Pattenden who provided able assistance throughout the field season, and R.A. Ryziuk for the drafting of the figures.

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Plate 4-6-1. Phosphate nodules (N) in sandstone in Johnson Canyon Formation, Cabin Creek area.

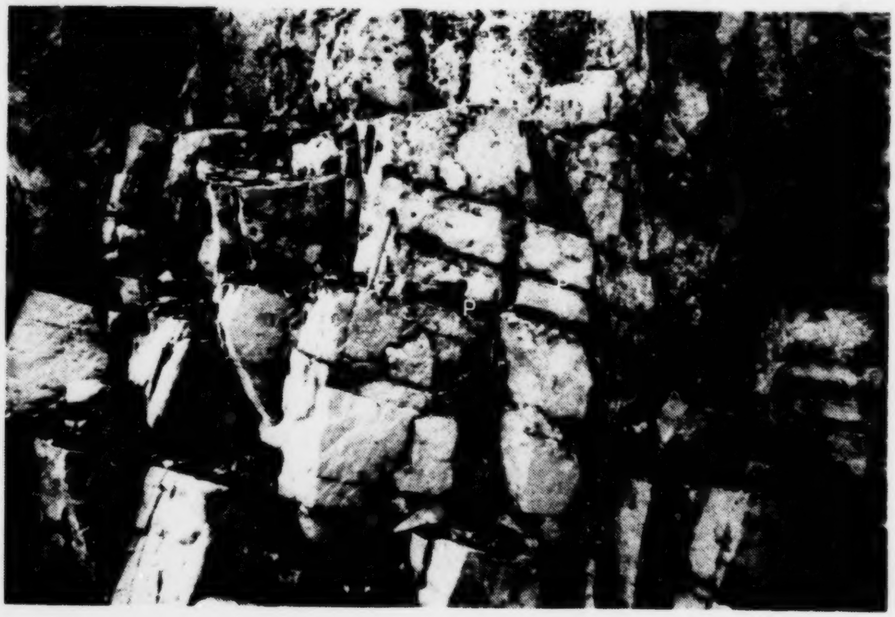

Plate 4-6-2. Phosphate laminae (P) in Telford Formation, Telford Creek area.

Plate 4-6-3. Phosphatic coquinoid bed (P) in Telford Formation, Telford Creek area.

Plate 4-6-4. Phosphate nodules (N) in a coquinoid bed, Ross Creek Formation.

Plate 4-6-5. Basal conglomerate with phosphate cement (P); Ranger Canyon Formation, Cabin Creek area.

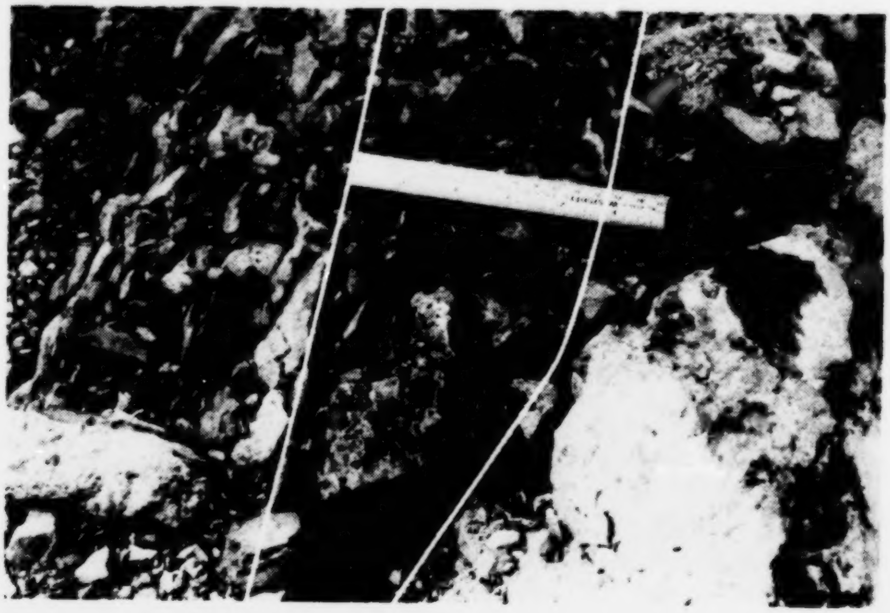

Plate 4-6-6. Phosphate bed at top of Ranger Canyon Formation, Fernie ski hill.

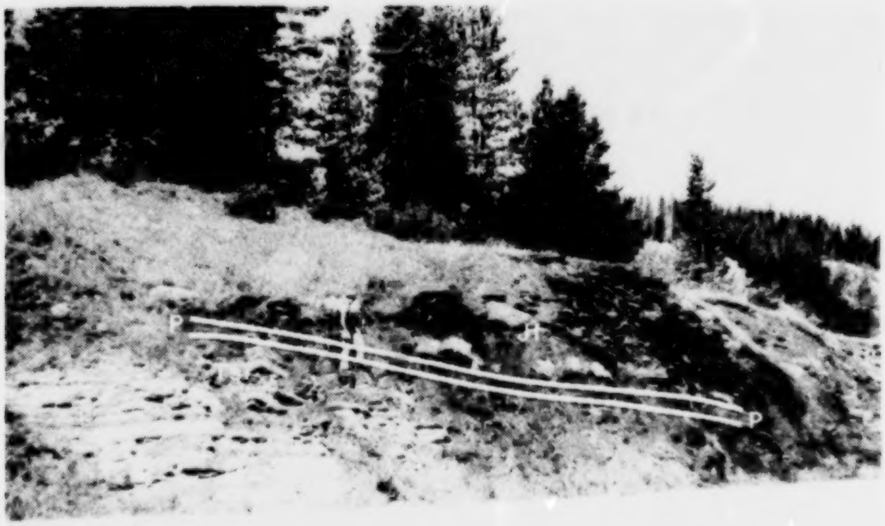

Plate 4-6-7. Basal phosphorite bed (P) in Fernie Formation shale (JF) overlying siltstone of the Sulphur Mountain Formation (Tsr), Highway 3 roadcut at Alexander Creek.

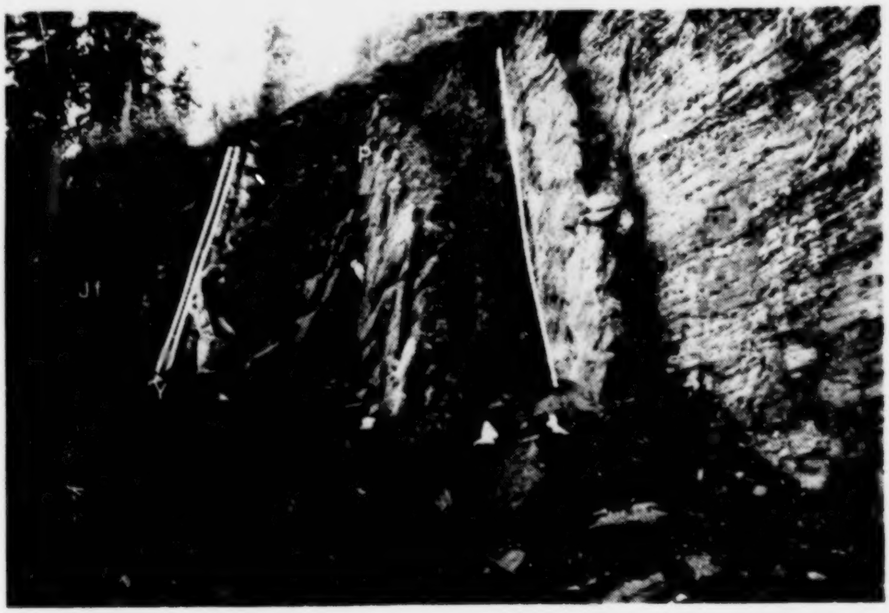

Plate 4-6-8. Basal phosphate horizon (P) in Fernie Formation shale (JF) overlying siltstone of the Sulphur Mountain Formation (Tsr), Mount Lyne, top of the phosphate marked by yellow-orange limestone bed (Y).

OLIVINE POTENTIAL IN THE TULAMEEN ULTRAMAFIC COMPLEX PRELIMINARY REPORT*
(92H/10)

By G.V. White

INTRODUCTION

Olivine, the essential constituent mineral of the rock dunite, has long been known to occur in the core of the Tulameen ultramafic complex. A project initiated in August 1986 was designed to evaluate whether this dunite is a suitable source of olivine for industrial applications. At present olivine used in Canada as a foundry and blasting sand is imported from the United States. The objectives of the investigation are:

(1) To locate fresh unserpentinized olivine (loss-on-ignition less than 2 per cent) in selectively mineable and accessible bodies within the Tulameen complex.

(2) To test whether the dunite will meet commercial specifications for foundry sand in refractory applications.

Preliminary results indicate occurrences of unaltered olivine in weakly serpentinized zones.

TOPOGRAPHY AND ACCESS

The dunite core of the Tulameen complex is situated in rugged steep terrain between Grasshopper Mountain on the north and Olivine Mountain to the south (Figure 4-7-1, Plates 4-7-1 and 4-7-2). Outcrop is good, particularly at higher elevations; lower slopes are covered by heavy second growth forest.

The study area is approximately 12.5 kilometres west of the village of Tulameen and accessible by truck along the Tulameen River road.

REGIONAL SETTING AND STRUCTURE OF THE COMPLEX

The Tulameen complex is an Alaskan-type zoned intrusion, forming a southeasterly elongated ultramafic-gabbroic body surrounded by the Upper Triassic Nicola Group metasedimentary and metavolcanic rocks (Findlay, 1969). It is overlain by terrigenous sedimentary rocks and andesitic flows of the Eocene Princeton Group (Rublee, 1986). The complex is considered Middle Jurassic in age based on potassium-argon dates of 186 million years on biotite and 174 ± 4 million years on hornblende (Rublee, 1986). The principal ultramafic units are dunite, olivine clinopyroxenite and hornblende clinopyroxenite which are thought to result from fractional crystallization of an ultrabasic magma (Findlay, 1969).

LOCAL GEOLOGY

The dunite core forms an oval-shaped body, with an area of approximately 6 square kilometres, which underlies most of Grasshopper and Olivine Mountains (Findlay, 1969). The dunite is buff to yellowish brown in colour and weathers light to dark grey. It is fine to medium grained (<1 millimetre to 1.5 millimetres) and contains visible serpentine (up to 80 per cent), pods of chromite (up to 2 centimetres wide by 30 centimetres long), and magnetite.

A geological sketch of the area is shown in Figure 4-7-2.

Chemical analyses of six samples of olivine (Fo_{86}-Fo_{93}) collected by Findlay (1963) from the core are provided in Table 4-7-1. These results compare favourably to analyses of commercial olivines from seven deposits in North America and Europe.

TABLE 4-7-1. COMPARISON OF CHEMICAL ANALYSES OF SOME COMMERCIAL OLIVINES WITH SAMPLE FROM THE TULAMEEN DEPOSIT
(per cent)

	1	2	3	4	5	6	7	8
MgO	47.5	43–44	49.0	47.7	46.4	46.9	48.09	47.1–48.9
SiO_2	40.4	24–35	42.5	40.8	42.5	40.8	40.28	39.3–40.0
Fe_2O_3	9.0	7.6–7.7	6.0	7.5	8.0	9.4	9.13*	9.25*
Other oxides	2.5	0.7–0.8	1.8	1.9	2.4	3.2	1.51	0.84–3.46
LOI	0.8	?	0.6	2.0	0.5	0.6	?	0.92

1 — Ste. Anne des Monts, Quebec, Canada (Lefond, 1983).
2 — Leoben, Austria (Lefond, 1983).
3 — Aaheim, Norway (Lefond, 1983).
4 — Norddal, Norway (Lefond, 1983).
5 — Burnsville, North Carolina, U.S.A. (Lefond, 1983).
6 — Hamilton, Washington, U.S.A. (Lefond, 1983).
7 — Twin Sisters, Washington, U.S.A. (Olivine Corp., Company Report).
8 — Tulameen Ultramafic Complex, B.C., Canada (Findlay, 1969).

* Total iron calculated as Fe_2O_3.

Sources: Findlay (1963); Lefond (1983); Olivine Corporation (1986).

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

SAMPLING PROGRAM

A sampling program by Findlay (1963) documented the intensity of serpentinization in the core of the Tulameen complex (Figure 4-7-1).

The 1986 program was designed to outline the least serpentinized part of the dunite core. In total 110 samples weighing 0.5 kilogram and three bulk samples (>100 kilograms) were collected.

RESULTS

(1) Nineteen of the 74 samples tested report a loss-on-ignition value of less than 2 per cent.

(2) Three zones with loss-on-ignition less than 2 per cent have been identified north of the Tulameen River on the southwest slope of Grasshopper Mountain (Figure 4-7-2). The northern zone, approximately 100 metres long by 75 metres wide, is open to the east. A second central zone is approximately 50 metres long by 40 metres wide and open to the west. The third, irregular zone, cut by the Tulameen River road, is approximately 100 metres long by 65 metres wide (maximum).

(3) Three isolated samples from north and south of the northern zone and west of the southern zone tested less than 2 per cent loss-of-ignition.

(4) All samples collected south of the Tulameen River on the north slope of Olivine Mountain have values greater than 2 per cent.

SUMMARY

The 1986 sampling and mapping program has outlined the presence of practically unserpentinized "fresh" dunite on the southwest slope of Grasshopper Mountain. Chemical analyses indicate it compares favourably with commercially produced olivine from around the world.

There is additional potential for reserves of relatively unaltered dunite, east of the sampled area on Grasshopper Mountain and on the north slope of Olivine Mountain in areas not yet sampled. Additional analytical tests on bulk samples are required to determine suitability for commercial applications of the olivine. These tests will determine specific gravity, hardness, melting point, and petrographic and chemical parameters.

ACKNOWLEDGMENTS

The author would like to acknowledge Z.D. Hora for suggesting the study. Field assistant David Hannay provided able and cheerful assistance in the field. The British Columbia Ministry of Energy, Mines and Petroleum Resources analytical laboratory carried out all loss-on-ignition tests Figures were drafted by Bob Ryziuk.

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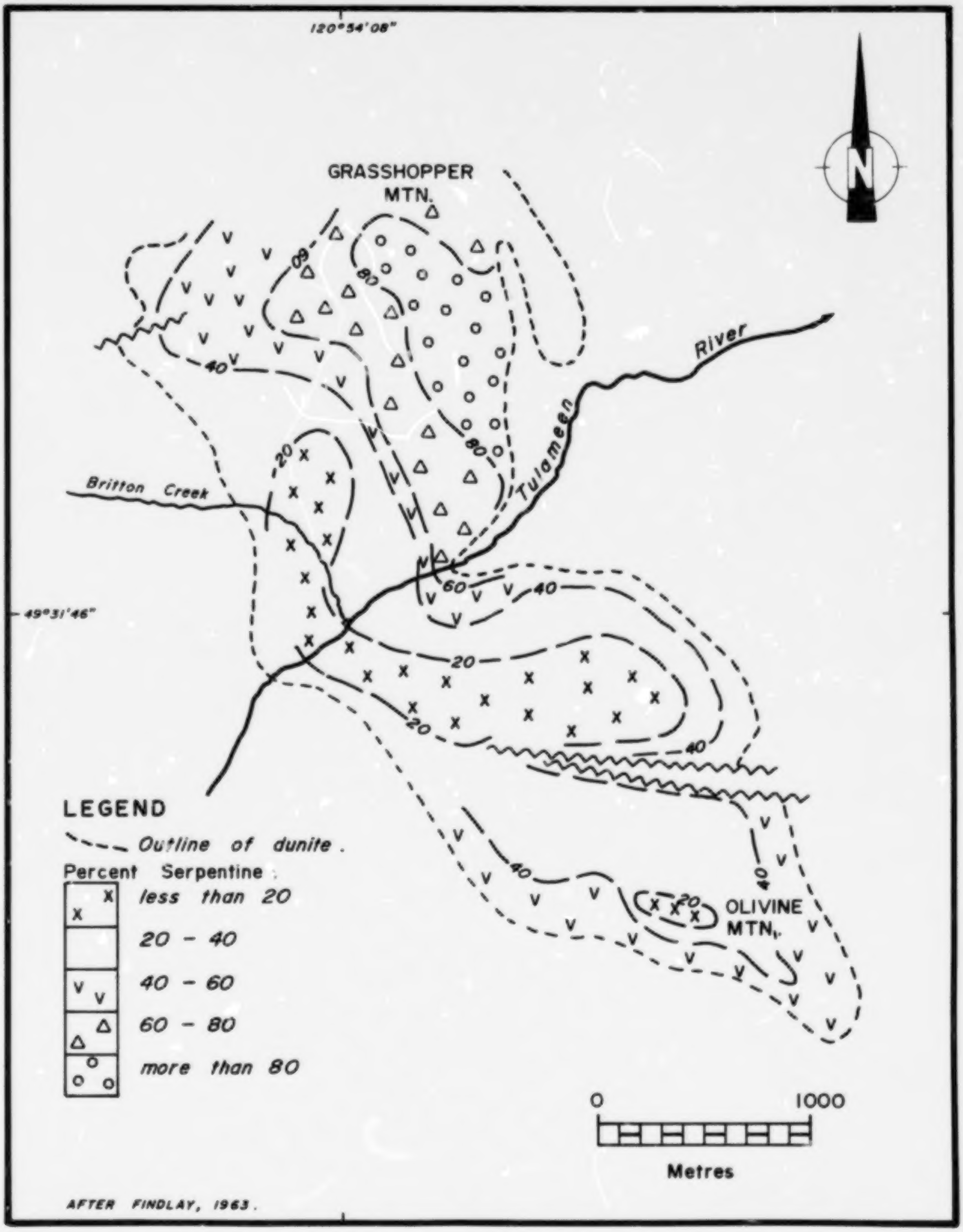
120°54'08"
N
GRASSHOPPER MTN.
60
80
40
River
Tulameen
20
Britton Creek
80
60
40
49°31'46"
20
20
40
40
20
OLIVINE MTN.
LEGEND
Outline of dunite.
Percent Serpentine:
less than 20
20 - 40
40 - 60
60 - 80
more than 80
0
1000
Metres
AFTER FINDLAY, 1963.

Figure 4-7-1. Serpentinized zones in the dunite core, Tulameen ultramafic complex.

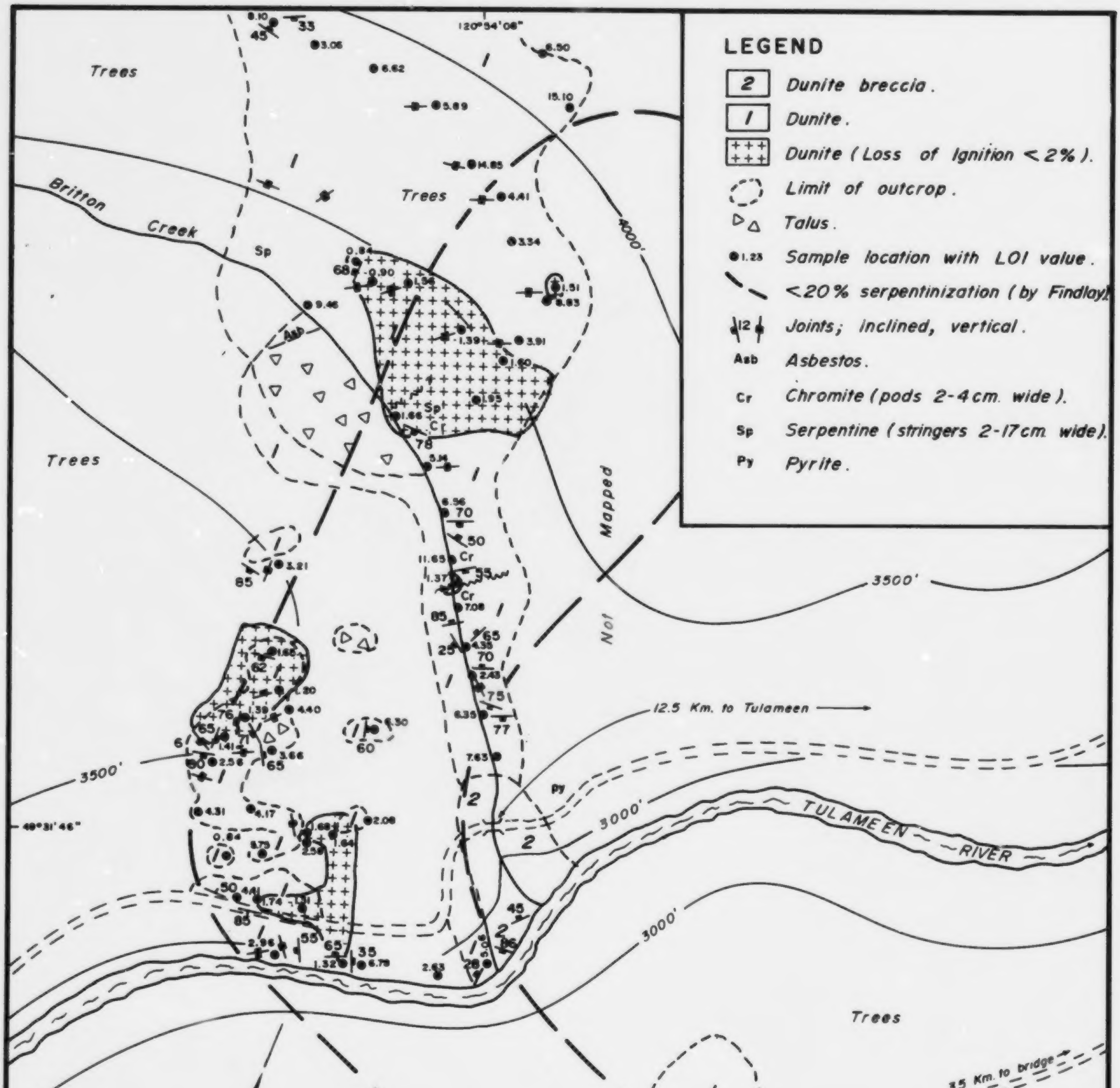
LEGEND
2 Dunite breccia.
1 Dunite.
+++ Dunite (Loss of Ignition < 2%).
Limit of outcrop.
Talus.
1.23 Sample location with LOI value.
<20% serpentinization (by Findlay).
12 Joints; inclined, vertical.
Asb Asbestos.
Cr Chromite (pods 2-4 cm. wide).
Sp Serpentine (stringers 2-17 cm. wide).
Py Pyrite.
120°54'06"
49°31'46"
Trees
Britton Creek
TULAMEEN RIVER
12.5 Km. to Tulameen
3.5 Km. to bridge
Not Mapped
3500'
3000'
4000'
N
0
150
Metres

Figure 4-7-2. Geological sketch map of the study area and sample locations with reported loss-on-ignition values.

Plate 4-7-1. Looking north up Britton Creek (92H/10).

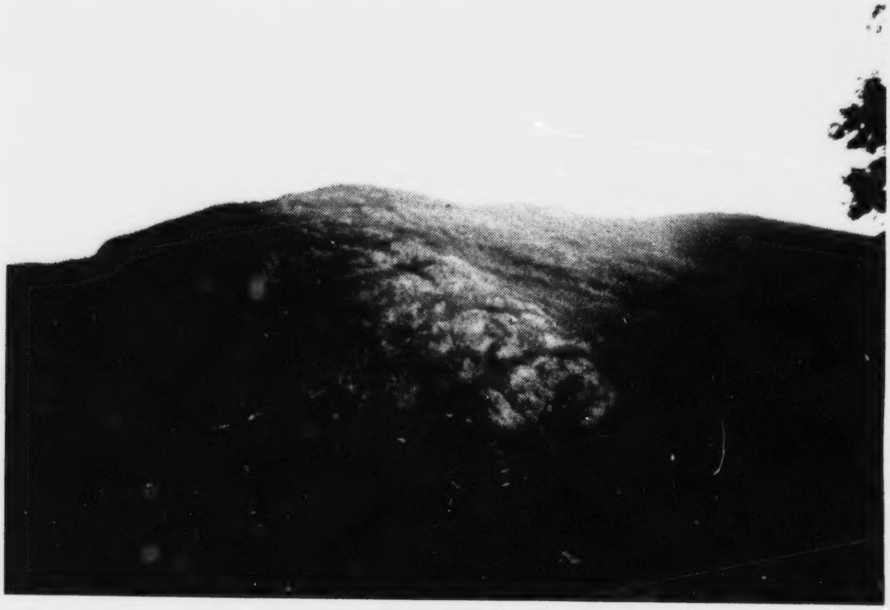

Plate 4-7-2. Olivine Mountain, looking south (92H/10).

DIMENSION STONE QUARRIES IN BRITISH COLUMBIA*

By G. V. White

INTRODUCTION

At the turn of the century British Columbia produced a variety of quality dimension stone for both domestic and foreign markets. The industry flourished until the 1930s when many of the producing quarries closed. At present most dimension stone used in British Columbia is imported.

The objectives of an evaluation of dimension stone sites around the province, carried out during 1985-1986, are:

(1) To identify dimension stone deposits with good development potential.

(2) To cut and polish sets of samples for promotional purposes.

(3) To promote significant deposits by producing brochures documenting the quality of the stone and the development potential of the sites.

This report describes 13 sites examined during 1986 (Figure 4-8-1). Descriptions are listed by geographical location rather than rock type, starting in eastern British Columbia.

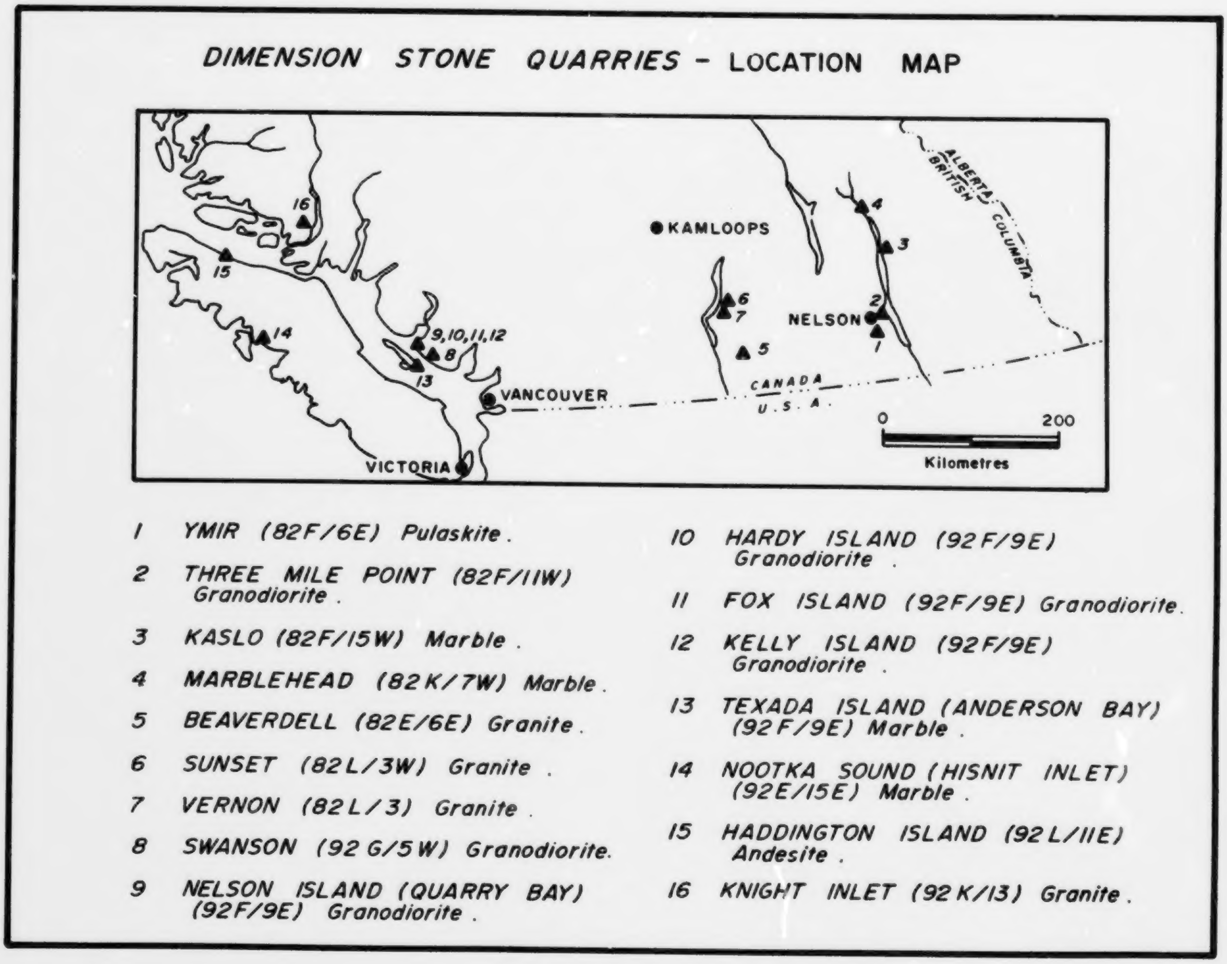
DIMENSION STONE QUARRIES - LOCATION MAP
KAMLOOPS
NELSON
VANCOUVER
VICTORIA
ALBERTA
BRITISH COLUMBIA
CANADA
U.S.A.
0
200
Kilometres
1 2 3 4 5 6 7 8 9,10,11,12 13 14 15 16
1 YMIR (82F/6E) Pulaskite.
2 THREE MILE POINT (82F/11W) Granodiorite.
3 KASLO (82F/15W) Marble.
4 MARBLEHEAD (82K/7W) Marble.
5 BEAVERDELL (82E/6E) Granite.
6 SUNSET (82L/3W) Granite.
7 VERNON (82L/3) Granite.
8 SWANSON (92 G/5 W) Granodiorite.
9 NELSON ISLAND (QUARRY BAY) (92F/9E) Granodiorite.
10 HARDY ISLAND (92F/9E) Granodiorite.
11 FOX ISLAND (92F/9E) Granodiorite.
12 KELLY ISLAND (92F/9E) Granodiorite.
13 TEXADA ISLAND (ANDERSON BAY) (92F/9E) Marble.
14 NOOTKA SOUND (HISNIT INLET) (92E/15E) Marble.
15 HADDINGTON ISLAND (92L/11E) Andesite.
16 KNIGHT INLET (92K/13) Granite.

Figure 4-8-1. Dimension stone location map.

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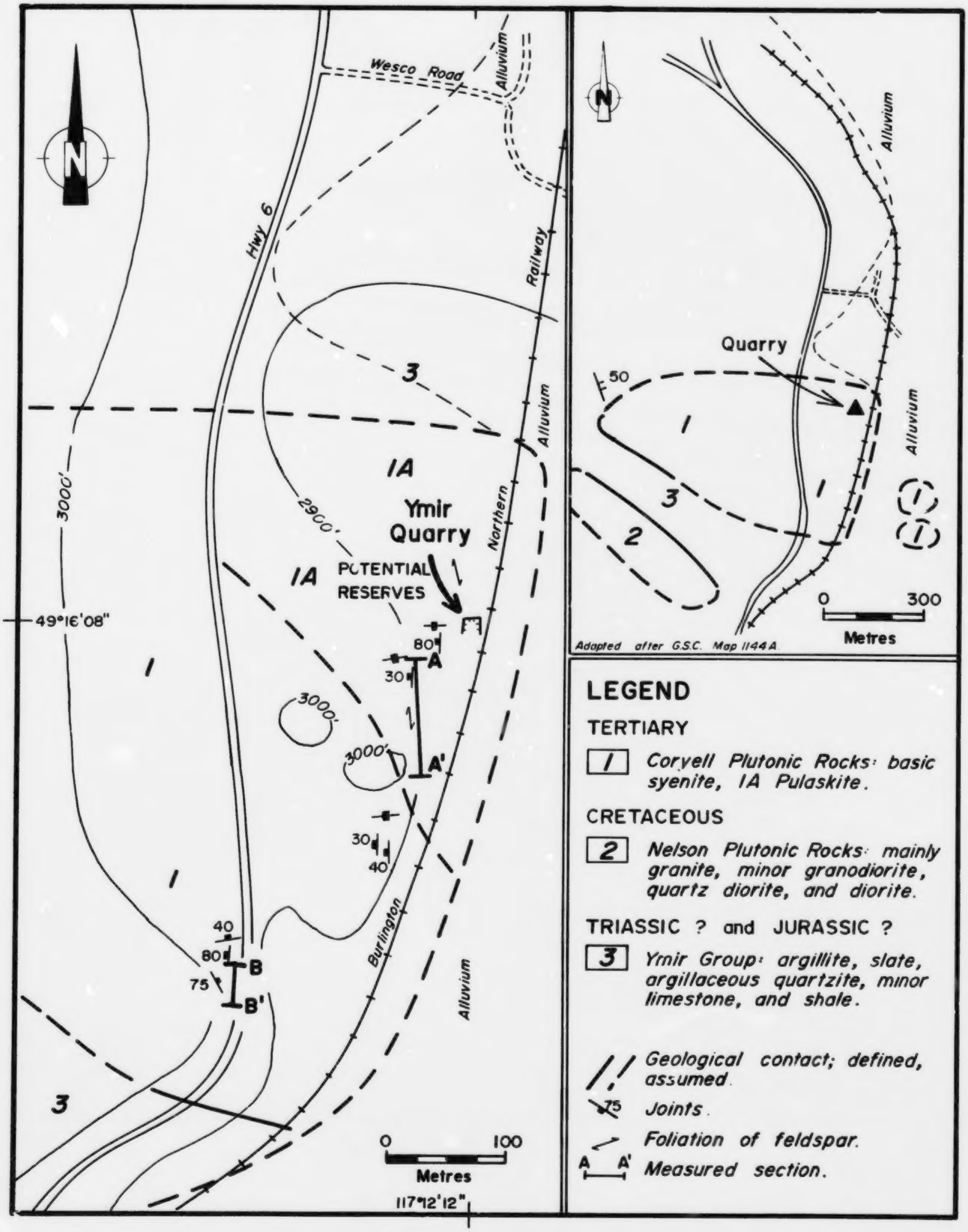
* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.



N
Wesco Road
Alluvium
Hwy 6
Railway
3
Alluvium
IA
3000'
2900'
Ymir Quarry
Northern
IA
POTENTIAL RESERVES
49°16'08"
80
A
30
I
3000'
3000'
A'
30
40
I
Burlington
40
80
B
75
B'
Alluvium
3
0
100
Metres
117°12'12"
N
Alluvium
Quarry
50
I
Alluvium
I
3
2
0
300
Metres
Adapted after G.S.C. Map 1144A
LEGEND
TERTIARY
I
Coryell Plutonic Rocks: basic syenite, IA Pulaskite.
CRETACEOUS
2
Nelson Plutonic Rocks: mainly granite, minor granodiorite, quartz diorite, and diorite.
TRIASSIC ? and JURASSIC ?
3
Ymir Group: argillite, slate, argillaceous quartzite, minor limestone, and shale.
Geological contact; defined, assumed.
75
Joints.
Foliation of feldspar.
A A'
Measured section.

Figure 4-8-2. Ymir quarry (82F/6E).

KOOTENAY QUARRIES

PULASKITE — YMIR QUARRY (82F/6E)

Introduction

An abandoned dimension stone quarry (Mineral Inventory 82F-297), located approximately 1.1 kilometres south of the village of Ymir, produced monument and ornamental stone intermittently through the first half of the century (Carr, 1955; Plate 4-8-1). Known locally as "Ymir Pearl", the stone can be seen in Nelson where it was used in construction of the War Memorial.

Sample Description

Pulaskite has been quarried from the core of a basic syenite plug of the Tertiary Coryell plutonic rocks (Little *et al.*, 1963).

On fresh surfaces the pulaskite is mauve-grey although euhedral phenocrysts of green to black diopside (1 to 6 millimetres) and black blades of biotite (1 to 3 millimetres) darken the tone of the rock. The matrix consists of rectangular feldspars (up to 4.5 centimetres by 3 millimetres) which Drysdale (1917) identified as intergrowths of orthoclase and albite. In outcrop the large elongate feldspars, which schillerize a brilliant sky blue when wet, are consistently oriented between 330 and 360 degrees.

Infrequent patches of pyrite and a red-brown iron stain, derived from weathered blades of biotite, are visible in places. Weathered surfaces have a dull appearance as does the polished face of the Nelson War Memorial.

Quarry Development

The quarry is horseshoe shaped and lies immediately west of the Burlington Northern railway tracks (Figure 4-8-2). The east wall parallels the track at a bearing of 10 degrees. It is approximtely 25 metres long and has a maximum height of 7 metres. The west wall is 14 metres long with a maximum height of 12.5 metres. The abandoned working face at the north end of the quarry is approximately 14 metres long and has a height of 4.6 metres.

The quarry is overgrown with heavy second growth forest and littered with large abandoned cut blocks.

Structure

The development of joints is irregular and difficult to predict. One main set strikes east and has a near-vertical dip. It is recognized both in the quarry and in outcrop to the south. A flat set strikes north and dips 30 degrees west but joints are irregular and not well defined.

Joint and fracture intensity varies within the plug. Along a 110-metre section of outcrop south of the quarry (A-A', Figure 4-8-2) over 79 per cent of vertical joints are spaced greater than 50 centimetres apart and over 64 per cent are spaced more than 100 centimetres apart. Seventy-five per cent of horizontal joints and fractures are spaced wider than 50 centimetres (Figure 4-8-3). Along a 30-metre section of outcrop near the southern contact of the syenite plug (B-B', Figure 4-8-2), 66 per cent of vertical and 83 per cent of horizontal joints and fractures are spaced less than 50 centimetres apart.

Discussion

Changes in joint and fracture density in different areas of the plug could be a reflection of the location of the section measured. Section A-A' measured near the centre of the plug was probably subject to less intense pressure than section B-B' located nearer the margin (Figures 4-8-2 and 4-8-3).

Physical Tests

Results of physical tests carried out on samples from the quarry are outlined in Table 4-8-2. The tests indicate that the stone does not meet American Society for Testing and Materials (ASTM) standards for modulus of rupture (traverse strength) for granite building stone, but does meet all other ASTM standards.

GRANODIORITE — THREE MILE POINT (82F/11W)

Introduction

An abandoned quarry (MI 82F-249) near Three Mile Point on the east shore of Kootenay Lake (Plate 4-8-2) provided stone for a number of prominent buildings and the Houston monument in Nelson (Parks, 1917).

Sample Description

The granodiorite, considered early Cretaceous in age, is part of the Nelson pluton (Little *et al.*, 1963). It is porphyritic, with scattered feldspar crystals up to 2 by 4.5 centimetres visible in places. The stone is medium to coarse grained, speckled with black blades of biotite (1 to 2 millimetres) and glassy grey to pink quartz crystals (1 millimetre to 1 centimetre) and has a light white to pink tone.

Minerals identified in thin section include plagioclase, orthoclase, quartz, biotite and minor magnetite. Parks (1917) reports small amounts of sphene although this mineral was not observed in thin section.

Exposed surfaces, such as the Houston monument in Nelson, appear fresh and retain the stone's attractive appearance.

Quarry Development

Three separate sites were worked along a ridge (Figure 4-8-4).

Site 1

Site 1 consists of three working faces developed in a series of steps. The faces, cut along northwest-striking, vertically dipping joints, measure 12.8, 7.9 and 17.6 metres in length and have maximum heights of 4.0, 1.3 and 3.5 metres. Vertical joints and fractures are spaced between 0.2 and 3 metres apart; flat joints, 0.2 to 1.3 metres apart, strike between 270 and 290 degrees and dip 35 to 40 degrees north.

Site 2

Site 2 consists of one working face, approximately 36.5 metres long by 7.5 metres high, which parallels a vertical joint striking 353 degrees. Irregularly spaced joints, striking 305 degrees and dipping 45 degrees north, are spaced approximately 1.3 metres apart although only a few are exposed. A second set of vertical joints strikes 270 degrees; joint spacing is irregular between 0.9 and 8.0 metres.

Site 3

The developed face at Site 3 measures 21.8 metres long by 20 metres high. It parallels a vertical joint which strikes 235 degrees. A few low-angle joints (averaging between 1.0 to 2.0 metres apart) strike 295 to 305 degrees and dip 40 degrees north.

Reserves

Limited outcrop between faces prevents a statistical analysis of the size of blocks available from the quarry. Measurements of cut blocks below each of the three sites suggest potential for large blocks.

Table 4-8-1 illustrates the size of blocks left on site. It is assumed that these were either too small or flawed and were rejected in favour of larger blocks. Excellent potential for quarriable granodiorite exists both along and between abandoned working faces and future development is possible to the east (Figure 4-8-4).

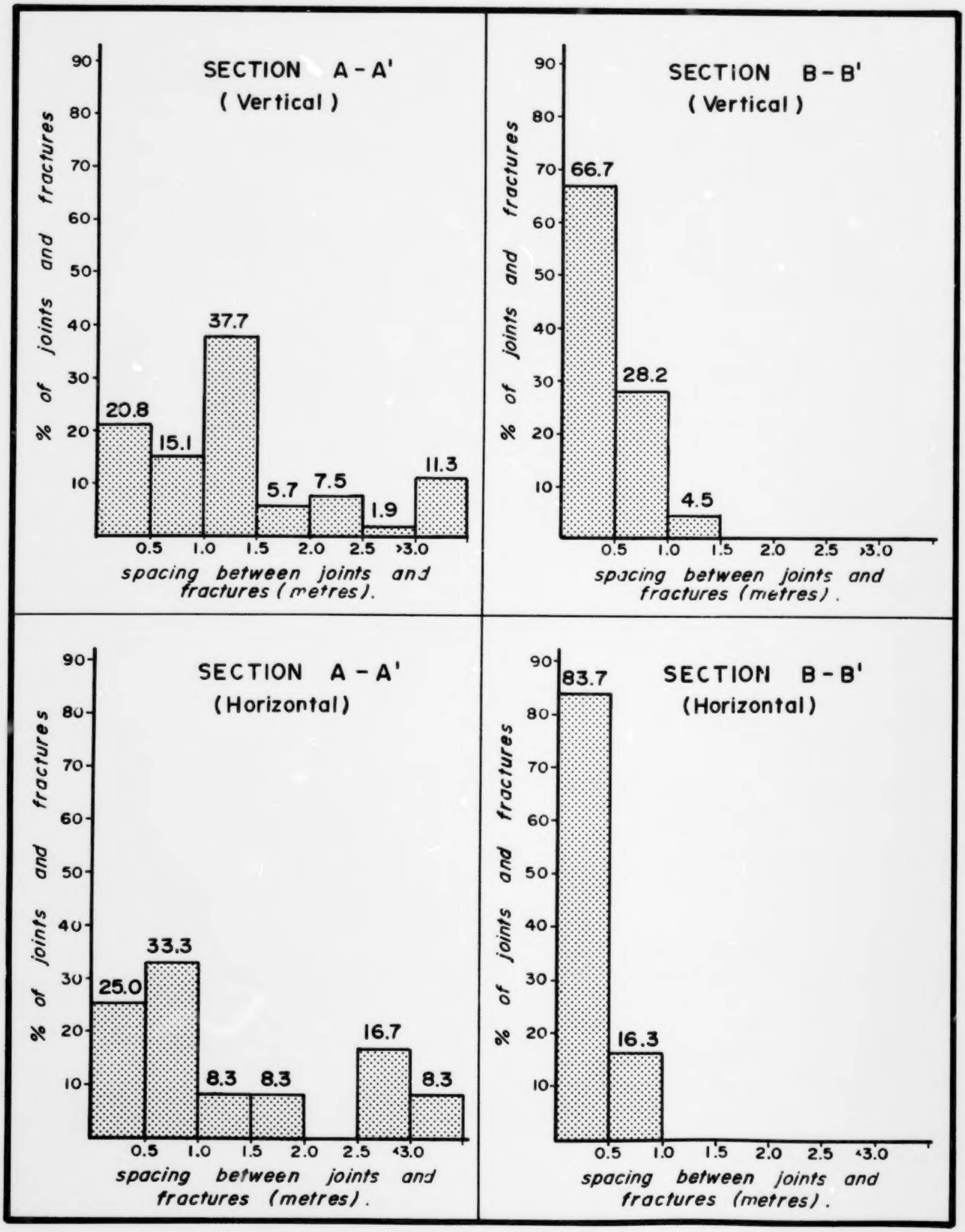


Figure 4-8-3. Ymir quarry histograms.

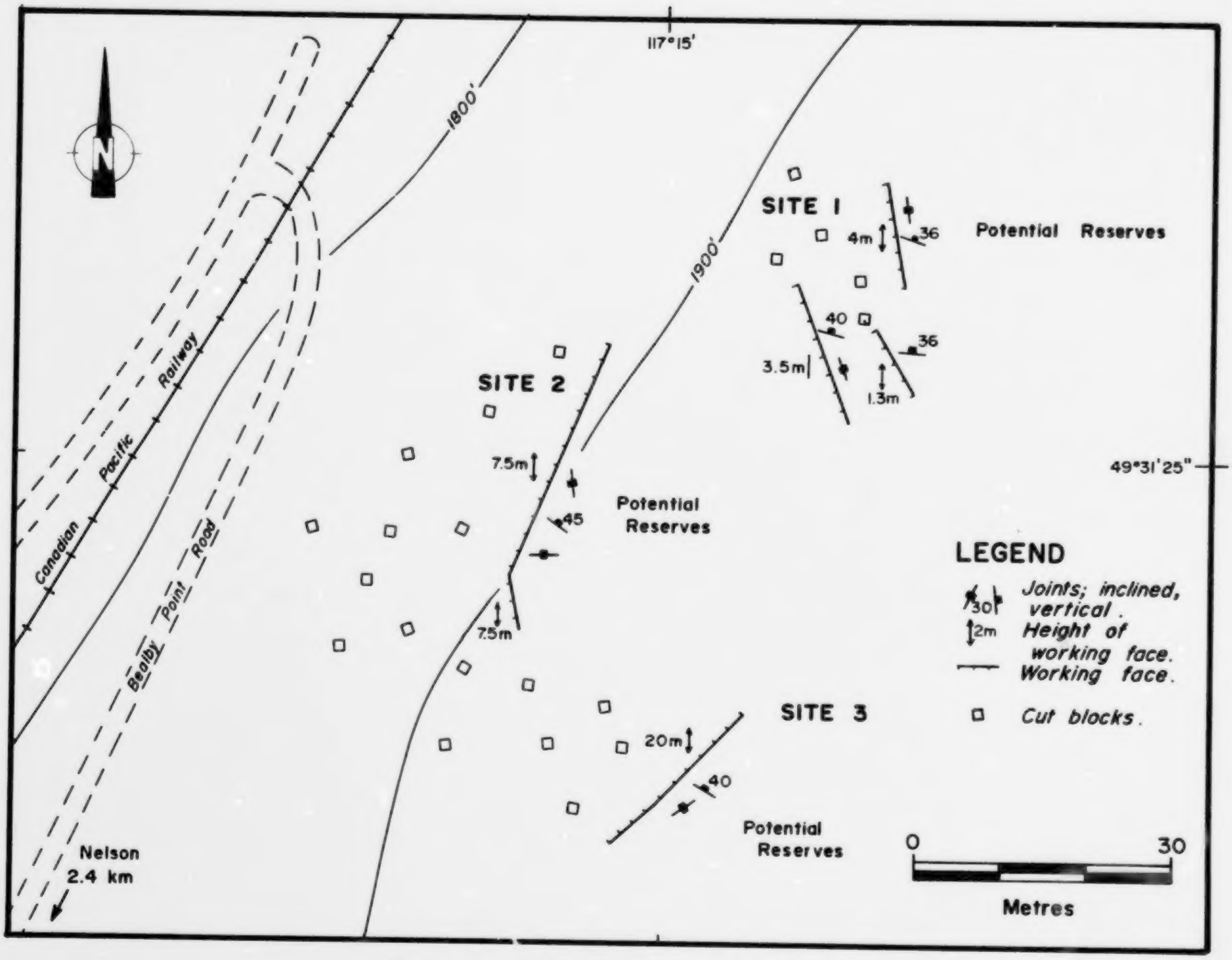

117°15'
N
1800'
1900'
SITE 1
4m
36
Potential Reserves
40
36
3.5m
1.3m
SITE 2
7.5m
45
Potential Reserves
7.5m
49°31'25"
LEGEND
30
Joints; inclined, vertical.
2m
Height of working face.
Working face.
Cut blocks.
SITE 3
20m
40
Potential Reserves
0
30
Metres
Canadian Pacific Railway
Bealby Point Road
Nelson 2.4 km

Figure 4-8-4. Three Mile Point quarry (82F/11W).

TABLE 4-8-1.
BLOCK SIZE, THREE MILE POINT QUARRY

Site*	Average Size of Cut Blocks (metres)
Site 1	0.99 × 0.62 × 0.35
Site 2	1.01 × 0.58 × 0.36
Site 3	1.11 × 0.62 × 0.50

* Based on 20 measurements at each site.

Physical tests reported by Parks (1917) on samples from this location indicate the stone meets ASTM standards for granite building stone (Table 4-8-2).

MARBLE — MARBLEHEAD QUARRIES (82K/7W)

Introduction

Four abandoned quarries (MI 82K-076), located approximately 3 kilometres north of the Meadow Creek bridge on Highway 31 south of Duncan Lake, produced white to grey-banded crystalline marble around the turn of the century. The marble was used in construction of a number of prominent buildings, including the attractive Bank of Commerce building in Nelson (Parks, 1917).

Quarry Development and Sample Description

All four quarries are located in crystalline limestone which crops out for about 1.5 kilometres north of Marblehead. The marble is part of the Lower Cambrian Badshot-Mohican Formation (Reesor, 1972).

Quarry 1

Quarry 1 is located 3.1 kilometres north of the Meadow Creek bridge, adjacent to Highway 31 (Figure 4-8-5 and Plate 4-8-3). The working face, 28.1 metres long, has a vertical height of 10.1 metres; the north and south walls are 10.4 metres and 12.7 metres long respectively.

The marble varies from an attractive milky white to bluish-grey in colour. At the quarry, the white variety dominates and the blue-grey marble occurs in distinct individual bands up to 18 centimetres wide within a 2.75-metre band near the base of the quarry. Both the light and dark marble, referred to as "Light Kootenay" and "Dark Kootenay" by Parks, are medium grained (1 to 4 millimetres) and contain no visible sulphides or other impurities.

In thin section the euhedral grains are seen to be interlocked and consist entirely of calcium carbonate. No other minerals were observed.

Remnant bedding, visible along the quarry walls, strikes 320 degrees and dips 35 to 40 degrees to the northeast. One set of joints strikes parallel to bedding and dips 45 to 55 degrees to the southwest. A second set, measured south of the quarry, strikes 190

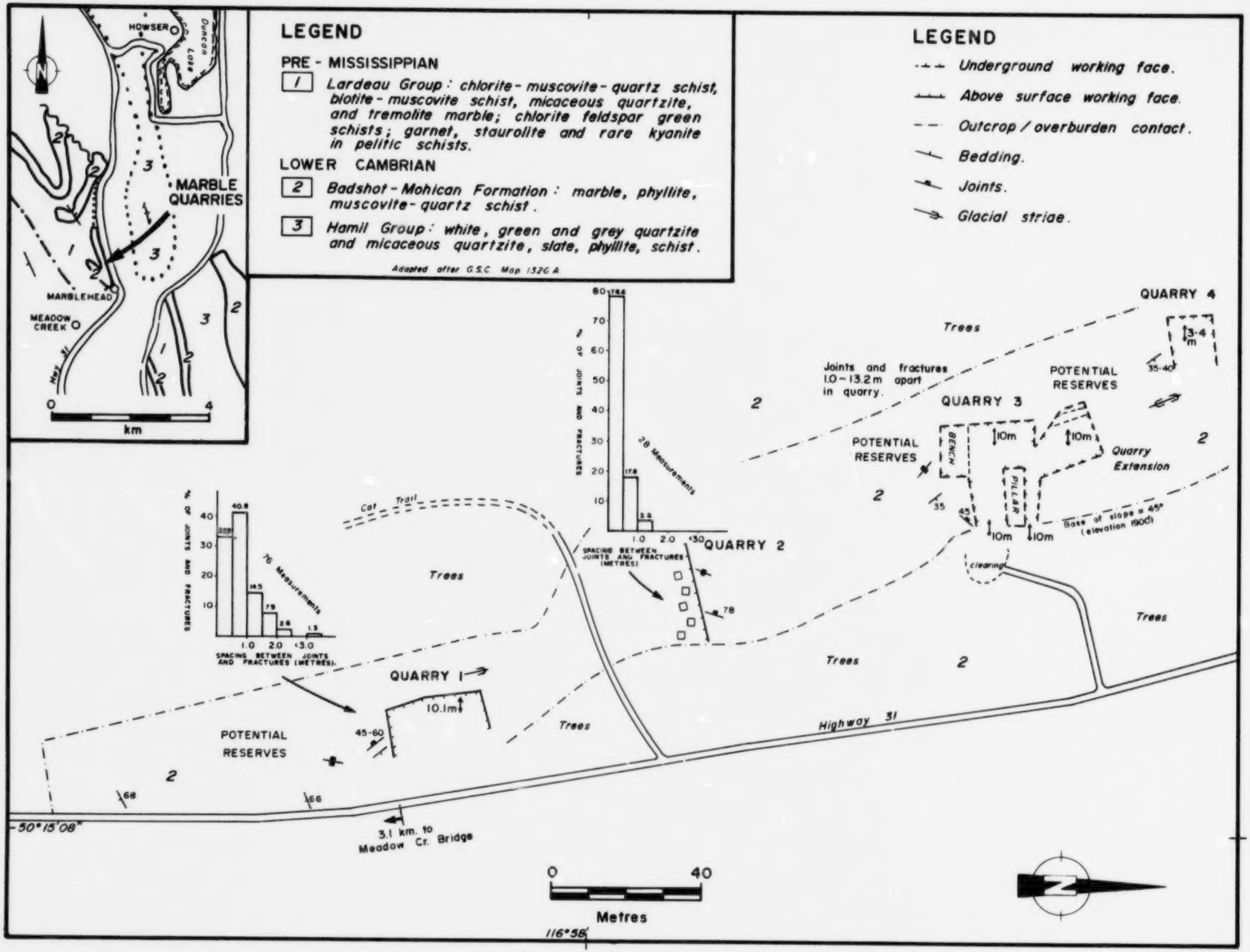

HOWSER
Duncan Lake
MARBLE QUARRIES
MARBLEHEAD
MEADOW CREEK
Hwy 31
1
2
3
0
4
km
LEGEND
PRE - MISSISSIPPIAN
1 Lardeau Group: chlorite-muscovite-quartz schist, biotite-muscovite schist, micaceous quartzite, and tremolite marble; chlorite feldspar green schists; garnet, staurolite and rare kyanite in pelitic schists.
LOWER CAMBRIAN
2 Badshot-Mohican Formation: marble, phyllite, muscovite-quartz schist.
3 Hamil Group: white, green and grey quartzite and micaceous quartzite, slate, phyllite, schist.
Adapted after G.S.C. Map 1326 A
LEGEND
Underground working face.
Above surface working face.
Outcrop / overburden contact.
Bedding.
Joints.
Glacial striae.
QUARRY 4
3-4 m
35-40
Trees
Joints and fractures 1.0 - 13.2 m apart in quarry.
POTENTIAL RESERVES
QUARRY 3
10m
10m
Quarry Extension
BENCH
PILLAR
POTENTIAL RESERVES
35
45
10m
10m
Base of slope ≈ 45° (elevation 1900)
clearing
Trees
% OF JOINTS AND FRACTURES
80
70
60
50
40
30
20
10
78.6
17.8
3.6
28 Measurements
1.0
2.0
<3.0
SPACING BETWEEN JOINTS AND FRACTURES (METRES)
QUARRY 2
78
% OF JOINTS AND FRACTURES
40
30
20
10
32.9
40.8
14.5
7.9
2.6
1.3
76 Measurements
1.0
2.0
<3.0
SPACING BETWEEN JOINTS AND FRACTURES (METRES).
Cat Trail
Trees
Trees
Trees
QUARRY 1
10.1m
45-60
POTENTIAL RESERVES
68
66
Highway 31
50°15'08"
3.1 km. to Meadow Cr. Bridge
0
40
Metres
116°58'
N
2

Figure 4-8-5. Marblehead quarries (82K/7W).

TABLE 4-8-2.
DIMENSION STONE QUARRIES IN BRITISH COLUMBIA, PHYSICAL PROPERTIES

Commodity	Quarry Name	NTS	Specific Gravity	Density lb/ft³	Density kg/m³	Absorption by Weight (per cent)	Compressive Strength PSI	Compressive Strength MPa	Traverse Strength (Modulus of Rupture) PSI	Traverse Strength (Modulus of Rupture) MPa
GRANITE[A]	Ymir[2]	82F/6E	2.69*	167.83*	2688*	0.35*	7,581 – 8,514	52.27 – 59.00	1,594 – 1,808	10.99 – 12.46
	Three Mile Point[1]	82F/11W	2.656	163.63	2621	0.407	29,406	203	1,708	11.78
	Beaverdell	82E/6E	2.61*	162.63*	2605*	0.50*	8,110 – 9,543	55.92 – 65.80	1,151 – 1,460	7.94 – 10.07
	Vernon	82L/3	2.67	164.30	2632	0.354	24,791	171	1,968	13.57
	Nelson Island[1]	92F/9E	2.657	164.82	2640	0.175	34,823	240	2,871	19.79
	Hardy Island[1]	92F/9E	2.703	167.56	2684	0.177	32,288	223	1,453	10.01
	Kelly Island[1]	92F/9E	2.681	166.33	2664	0.178	35,144	242	3,521	24.28
	Knight Inlet		3.05	—	—	0.113	—	—	4,075	28.10
MARBLE[B]	Marblehead	82K/7W	2.718	168.70	2702	0.179	12,486	86	2,127	14.67
	Kaslo	82F/15W	2.752	171.36	2745	0.99	13,987	96	1,254	8.65
	Nootka Sound	92E/15E	2.721	169.39	2713	0.073	18,992	131	2,349	16.20
	Texada Island (Anderson Bay)**	92F/9E	2.712	169.00	2707	0.052	18,518	128	2,466	17.00
ANDESITE	Haddington Island**	92L/11E	2.67	143.41	2297	3.79	18,428	127	1,160	8.00
PHYSICAL REQUIREMENTS — AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)										
GRANITE (*See* Definition)			N/A	160 (min)	2560	0.40 (max)	19,000 (min)	131	1,500 (min)	10.34
MARBLE (Calcite) (*See* Definition)			N/A	162 (min)	2595	0.75 (max)	7,500 (min)	52	1,000 (min)	7.00

* Average of three tests.

** Report published in Exploration in British Columbia, 1985, Part B.

[1] Granodiorite.

[2] Pulaskite.

GRANITE[A] (Commercial Definition) — a visibly granular, igneous rock generally ranging in colour from pink to light or dark grey and consisting mostly of quartz and feldspars, accompanied by one or more dark minerals. The texture is typically homogeneous but may be gneissic or porphyritic.

MARBLE[B] (Commercial Definition) — a crystalline rock composed predominantly of one or more of the following minerals: calcite, dolomite or serpentine and capable of taking a polish.

Source: 1984 Annual Book of ASTM Standards.

Conversion Factors:

PSI → MPa = # × 6.894 757 × 10^3

lb/ft³ → kgm³ = # × 1.601 846 × 10

Physical Tests: Ymir and Beaverdell tests; B.C. Ministry of Transportation and Highways (Geotechnical and Materials Branch). All other tests results, Parks (1917).

degrees and has a vertical dip. Parks describes the marble as "free from flaws and cracks and so unbroken that blocks can be taken out in size up to any dimension", however vertical fractures measured along the abandoned working face range between 0.25 and 3.1 metres apart. As illustrated in Figure 4-8-5, 67 per cent of cut blocks south of the quarry will be greater than 50 by 50 by 50 centimetres in size.

Quarry 2

This site is located approximately 80 metres northwest of Quarry 1 (Figure 4-8-5). No well-defined quarry exists at this location; it appears that small amounts of highly fractured grey marble were selectively removed in an unsuccessful attempt to find a more competent stone. A 27-metre section of dark grey, medium-grained crystalline limestone was examined. Joints and fractures have an average strike of 20 to 22 degrees and dip steeply to the west. Spacing between fractures is 10 to 70 centimetres, with an average spacing of 35 centimetres. Nearly 80 per cent of fractures are less than 50 centimetres apart (Figure 4-8-5).

Quarry 3

Quarry 3 lies 0.75 kilometre north of Quarry 1 along Highway 31 (Figure 4-8-5). This quarry, an underground operation (Plate 4-8-4), has the following dimensions:

South Portal: 14 metres long, 8 metres wide and approximately 10 metres high.

North Portal: 14.8 metres long, 3.5 metres wide and approximately 10 metres high.

Main Quarry: 24.9 metres long, 11.3 metres wide and approximately 10 metres high.

Quarry Extension: 11.1 metres long, 11.2 metres wide and approximately 10 metres high.

Bedding strikes 320 degrees, dipping between 35 and 40 degrees to the northeast and joints are not uniformly spaced. The entrance to the south portal is intensely fractured for the first 3 metres with fractures spaced 20 to 40 centimetres apart. Underground, joints and fractures measured along the south and west walls of the quarry are widely spaced, ranging between 1.0 and 13.2 metres apart.

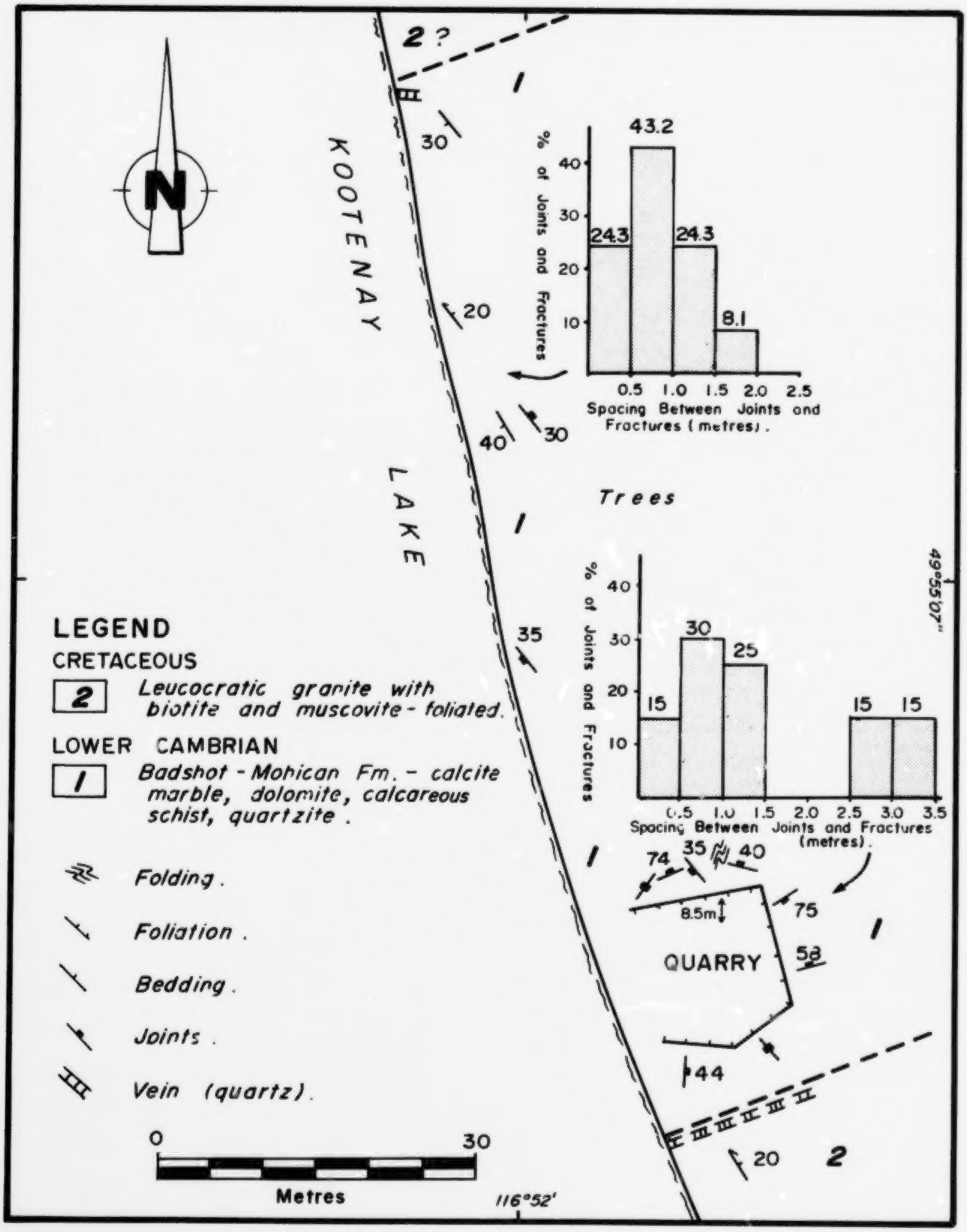

N
2 ?
KOOTENAY LAKE
30
20
40
30
35
Trees
74
35
40
8.5m
75
58
QUARRY
44
20
2
1
% of Joints and Fractures
10
20
30
40
24.3
43.2
24.3
8.1
0.5 1.0 1.5 2.0 2.5
Spacing Between Joints and Fractures (metres).
% of Joints and Fractures
10
20
30
40
15
30
25
15
15
0.5 1.0 1.5 2.0 2.5 3.0 3.5
Spacing Between Joints and Fractures (metres).
49°55'07"
116°52'
LEGEND
CRETACEOUS
2 Leucocratic granite with biotite and muscovite - foliated.
LOWER CAMBRIAN
1 Badshot - Mohican Fm. - calcite marble, dolomite, calcareous schist, quartzite.
Folding.
Foliation.
Bedding.
Joints.
Vein (quartz).
0
30
Metres

Figure 4-8-6. Kaslo quarry (82F/15W).

The marble is dominantly white, similar to the stone described at Quarry 1. Smaller amounts of the blue-grey banded variety are present and could be selectively worked.

Quarry 4

Quarry 4, located approximately 65 metres northwest of the south portal of Quarry 3, is an underground opening measuring 13.9 metres along its south and north walls, 12.2 metres along the working face and between 3 and 4 metres high.

Marble near the entrance is generally white, similar to marble described at Sites 1 and 3. Approximately 7 metres into the opening, the marble darkens to a grey colour and is cut by white calcite stringers, up to 18 centimetres wide, but averaging 1 centimetre in width. The grey marble is medium grained, banded, and not as attractive as the white variety.

On the south and west faces fractures spaced between 0.35 and 1.4 metres apart show no regular pattern. Remnant bedding appears to strike 320 degrees dipping 35 to 40 degrees to the northeast.

Reserves

Potential reserves of white to grey marble lie north, south and west of Quarry 1 (Plate 4-8-3). Preliminary results suggest cut blocks greater than 50 by 50 by 50 centimetres may be obtained from this area. Grey-banded marble from Quarry 2 will be restricted to blocks less than 50 by 50 by 50 centimetres in size. Large cut blocks of white to grey-banded marble, up to 13 metres long, are potentially available immediately adjacent to Quarry 3. Limited quantities of white marble and small blocks of grey marble are potentially available adjacent to Quarry 4.

There is excellent potential for reserves of dimension stone west of all four quarries although a heavy forest cover prevents detailed observation of this marble.

Physical testing of the marble, reported by Parks in 1917, indicates both varieties of white and grey marble meet ASTM standards for marble building stone (exterior) (Table 4-8-2).

MARBLE — KASLO
(82F/15W)

Introduction

Crystalline limestone from a small quarry located on the east shore of Kootenay Lake opposite Kaslo (Lot 2278), was used to construct the Nelson City Hall (formerly the courthouse) and other buildings around the turn of the century (Parks, 1917). Recent examination of the site has outlined reserves of attractive white to grey marble, suitable as dimension stone (Figure 4-8-6 and Plate 4-8-5).

Sample Description and Quarry Development

Crystalline limestone, considered part of the Badshot-Mohican Formation of Early Cambrian age (T. Höy, personal communication, 1986) varies in colour from white to blue-grey. The stone is coarse grained (greater than 5 millimetres), with individual crystals up to 16 millimetres in size. Parks observed "the stone is charged with tremolite" and has a "tendency to turn yellow, and later brown" on weathered surfaces. Examination of the Nelson City Hall and the government building in Kaslo confirms this observation. Samples from the quarry tested by Parks indicate the marble meets ASTM standards for marble building stone (exterior) (Table 4-8-2).

The quarry has a horseshoe shape and is approximately 13 metres long by 14 metres across by 8.5 metres high (maximum).

Structure

Joints are irregular, striking between 0 and 90 degrees with dips varying from 60 to 90 degrees northwest. Remnant bedding strikes 320 degrees and dips 35 to 40 southwest towards the lake (Figure 4-8-6).

Eighty-five per cent of joints and fractures measured are spaced more than 50 centimetres apart. North of the quarry approximately 75 per cent of joints and fractures are spaced wider than 50 centimetres.

Reserves

Potential reserves of marble, similar to stone in the quarry, are outlined north of the opening on the shore of the lake. Although more intensely fractured than stone in the quarry, preliminary results indicate the marble is suitable as a dimension stone (Figure 4-8-6).

East of the quarry the marble is covered by heavy second growth forest and was not examined in detail. To the south, a well-defined granite/marble contact marks the limit of the Badshot-Mohican Formation (Figure 4-8-6).

SUMMARY — KOOTENAY QUARRIES

(1) Physical tests on samples from the Ymir quarry indicate the stone does not meet ASTM standards for modulus of rupture. Stone from the Three Mile Point, Marblehead and Kaslo quarries meet all ASTM requirements for granite and marble building stone.

(2) Based on the measurements of cut blocks at the Three Mile Point quarry and fracture density surveys at the Ymir, Marblehead and Kaslo quarries, a significant proportion of potential reserves could be cut into blocks suitable for dimension stone applications.

(3) Stone from the Ymir and Three Mile Point quarries is suitable for building and ornamental purposes while marble from Marblehead and Kaslo could be used to produce facing stone and terrazzo tiles.

INTERIOR QUARRIES

GRANITE — BEAVERDELL QUARRY
(82E/6E)

Introduction

A brief geological description of the Beaverdell granite quarry (MI 82E-169), 14 kilometres south of Beaverdell, was published in *Exploration in British Columbia, 1985*, Part B (White, 1986). Recent examination indicates reserves of dimension stone are located north of the worked face (Plate 4-8-6).

Sample Description

Granite examined north of the quarry is considered part of the Valhalla intrusive complex of Mesozoic age (Little, 1961). The stone has a pink tone and is coarse grained and porphyritic with phenocrysts of pink orthoclase feldspar (3.5 by 6 centimetres) common. Other minerals include plagioclase, quartz, biotite and hornblende. Immediately north of the working face the granite is cut by at least one biotite-feldspar porphyry dyke 5 to 10 metres wide (Figure 4-8-7).

Structure and Reserves

Fracture intensity appears to increase northwest of the quarry (Figure 4-8-7), where 42 per cent of joints and fractures are spaced less than 50 centimetres apart and 67 per cent are spaced less than 100 centimetres apart.

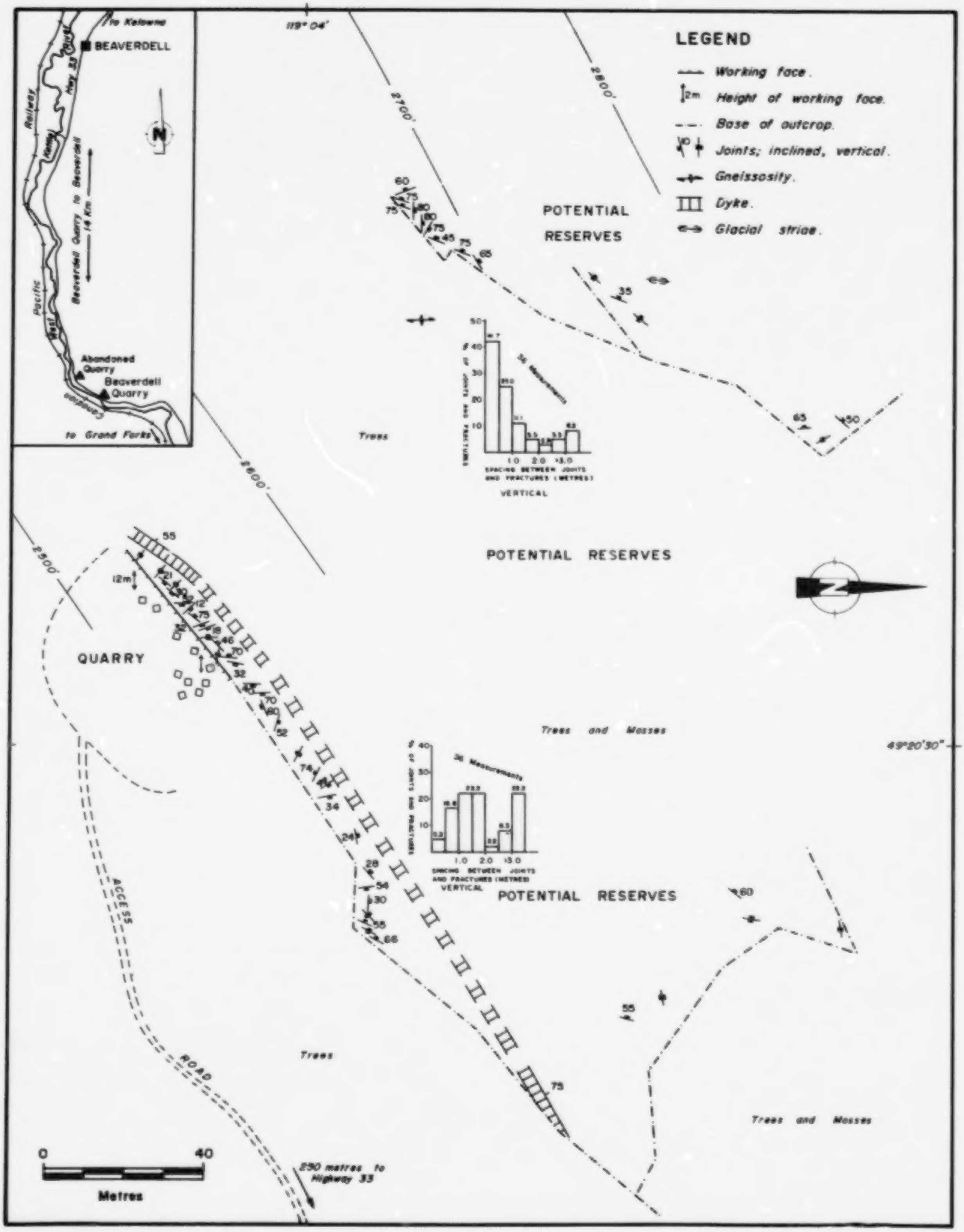

to Kelowna
BEAVERDELL
Hwy 33
River
Railway
Kettle
Beaverdell Quarry to Beaverdell
14 Km
Pacific
West
Abandoned Quarry
Beaverdell Quarry
Canadian
to Grand Forks
N
119° 04'
2700'
2800'
2600'
2500'
LEGEND
Working face.
2m Height of working face.
Base of outcrop.
Joints; inclined, vertical.
Gneissosity.
Dyke.
Glacial striae.
POTENTIAL RESERVES
POTENTIAL RESERVES
POTENTIAL RESERVES
Trees
Trees and Mosses
Trees
Trees and Mosses
QUARRY
12m
ACCESS ROAD
250 metres to Highway 33
49°20'30"
# of joints and fractures
36 Measurements
Spacing between joints and fractures (metres)
VERTICAL
50
40
30
20
10
1.0
2.0
>3.0
36 Measurements
0
40
Metres

Figure 4-8-7. Beaverdell quarry (82E/6E).

Northeast of the quarry, over 94 per cent of joints and fractures are spaced more than 50 centimetres apart and 78 per cent are spaced wider than 100 centimetres.

Physical Tests

Samples tested do not meet ASTM standards for granite building stone. The results listed in Table 4-8-2 indicate the rate of absorption is higher than the 0.40 per cent standard. The compressive strength of the three samples tested was below the standard 19,000 pounds per square inch (131 MPa) minimum limit and two of the three samples were below the minimum standard of 1500 pounds per square inch (10.34 MPa) for modulus of rupture.

Further testing of stone is required to confirm the modulus of rupture test as these results are based on only three samples rather than six, as recommended.

GRANITE — OKANAGAN SUNSET QUARRY (82L/3W)

Introduction

A granite quarry (MI 82L-068) approximately 4.4 kilometres northeast of Ellison Provincial Park on the east shore of Okanagan Lake is described in *Exploration in British Columbia, 1985*, Part B (White, 1986; Plate 4-8-7). Field examination during 1986 confirmed reserves of dimension stone to the northeast of the abandoned face (Plate 4-8-8).

Sample Description

The granite is part of the Nelson intrusive complex of Mesozoic age (Okulitch, 1979). Fresh stone has an attractive pale pink tone, is medium to coarse grained and contains pink orthoclase feldspar crystals up to 8 millimetres in length. Weathered surfaces are light to dark grey with occasional yellow iron stain. Similar stone from the Vernon quarry (82L/3W), used to build the Vernon courthouse, remains fresh and attractive after more than 60 years, attesting to the quality of the granite.

Potential Reserves

A well-defined ridge of granite, 80 metres long, 25 metres wide and up to 20 metres high (Figure 4-8-8), extends northeast of the abandoned working face. Joints measured along the ridge strike north-northwest and dip 70 degrees west to vertical. A second set, measured at both ends of the ridge, strikes east and dips between 55 and 90 degrees to the north while less steeply dipping, irregular joints along the southern margins of the outcrop strike northwest and dip 30 to 40 degrees southwest.

Spacing between joints and fractures measured along the ridge is irregular although 48 per cent are spaced greater than 50 centimetres apart. Horizontal fractures, visible only on the exposed face, are widely spaced, between 1.0 and 6.0 metres apart. Fractures measured along the margin of the outcrop are closely spaced, between 10 and 30 centimetres apart (Figure 4-8-8).

GRANITE — VERNON QUARRY (82L/3W)

Introduction

A granite quarry (MI 82L-087) on the east shore of Okanagan Lake, 200 metres south of Ellison Provincial Park, provided dimension stone for the Vernon courthouse (Parks, 1917) (Plate 4-8-9).

Sample Description

The granite is part of the Mesozoic Nelson intrusive complex (Okulitch, 1979). It is coarse grained with a fresh light pink tone; minerals visible in hand specimen include orthoclase, plagioclase, quartz, biotite and hornblende. Quartz stringers 2 to 3 centimetres wide by 3 to 4 metres long, cut the granite in the quarry face. Isolated patches of red iron stain are present on the outcrop.

Quarry Development and Structure

The working face, approximately 45 metres long by 10 metres high (Figure 4-8-9), was developed along prominent joints striking north to north-northeast and dipping steeply west. Other irregular north-striking joints dip moderately to steeply east. Well-developed east-west joints at the middle and south end of the face, dip steeply north. Flat joints exposed at the centre of the quarry strike northeast and dip gently south.

Spacing between vertical joints and fractures varies from 0.2 to 2.5 metres with no consistent pattern. Parks indicates blocks up to "15.6 by 3 by 2 feet" were selectively recovered although "great amounts of unmarketable material must be removed to obtain a limited amount of dimension stone". Documentation of joint and fracture spacing along the quarry face indicates nearly 60 per cent of recoverable blocks would be larger than 50 by 50 by 50 centimetres (Figure 4-8-9).

Reserves

Potential reserves of fresh granite extend 14 metres east of the abandoned working face along a prominent ridge (Figure 4-8-9). North of the quarry, granite crops out along the lakeshore within Ellison Provincial Park. Samples tested by Parks (1917) meet ASTM standards for granite building stone (Table 4-8-2).

SUMMARY — INTERIOR QUARRIES

(1) Physical tests on selected samples from the Beaverdell quarry indicate the granite does not meet ASTM standards for modulus of rupture and rate of absorption. Rock from the Vernon quarry meets all ASTM standards for granite.

(2) Based on fracture density surveys and examination of exposed outcrop, potential reserves of granite at the Beaverdell and Sunset quarries and limited reserves at the Vernon quarry have been documented. This stone is suitable for building and ornamental purposes.

COAST QUARRIES

GRANODIORITE — SWANSON QUARRY (92G/5W)

Introduction

A small quarry (MI 92G-008), approximately 1 kilometre west of Sechelt, produced paving stone prior to World War 1 (Figure 4-8-10; Parks, 1917). The quarry was opened in granodiorite of the Coast Plutonic Complex (Roddick *et al.*, 1979).

Quarry Development and Sample Description

The quarry (Plate 4-8-10), developed parallel to north-trending joints, has a maximum length of 75 metres along its north-south working face and 30 metres along its east-west face. A smaller face, approximately 25 metres north of the larger opening, is 25 metres long (Figure 4-8-10). The maximum height of developed faces is 3 metres.

The granodiorite is medium to coarse grained with a fresh appearance and a light tone. Exposed surfaces weather light grey and visible minerals include feldspar, quartz, biotite and hornblende. Occasional dark knots of mafic minerals and infrequent iron stains from weathered blades of biotite are visible on fresh surfaces. Pyrite and molybdenum were observed in one sample of float from near a "granite dyke", but neither mineral was found in place.

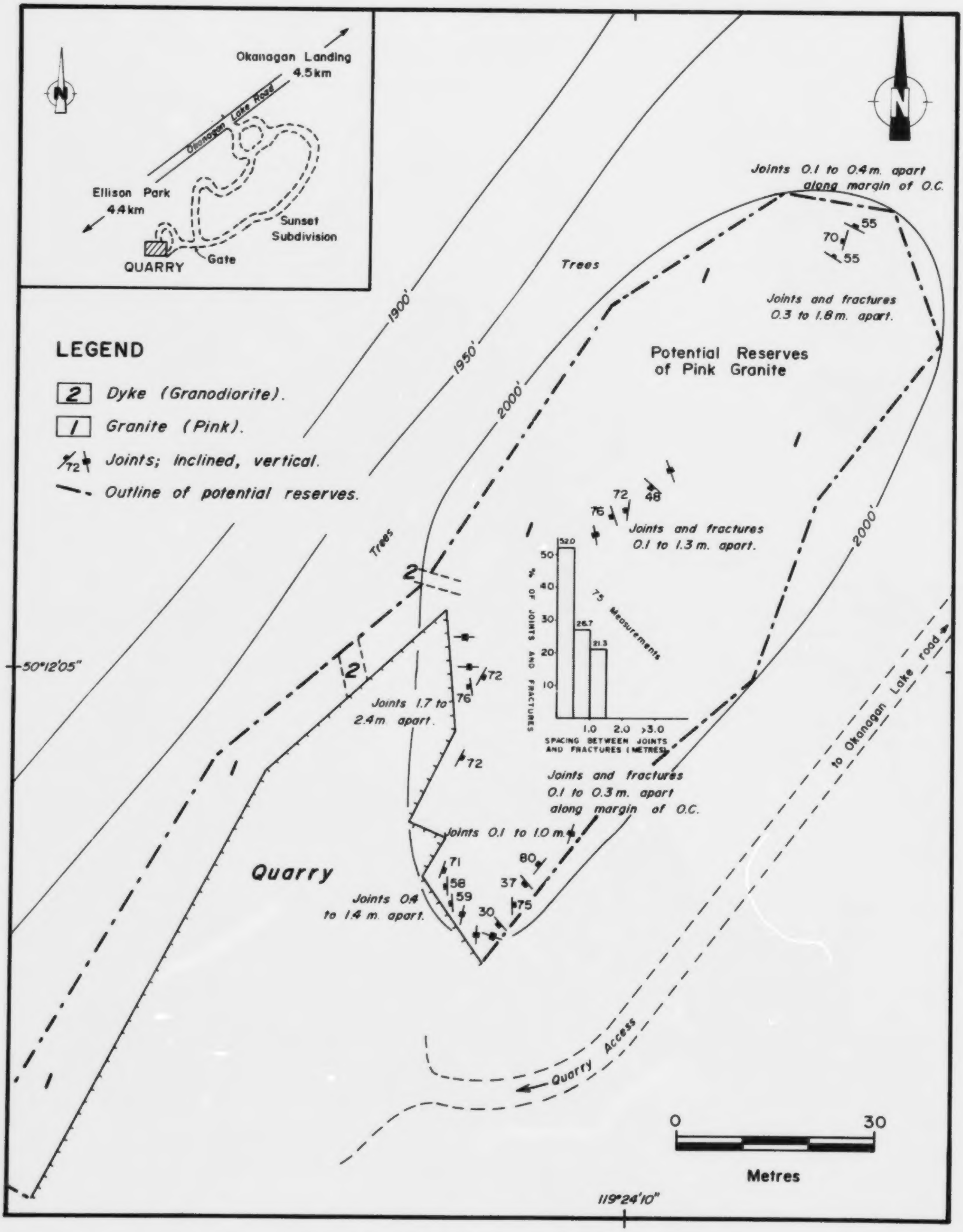
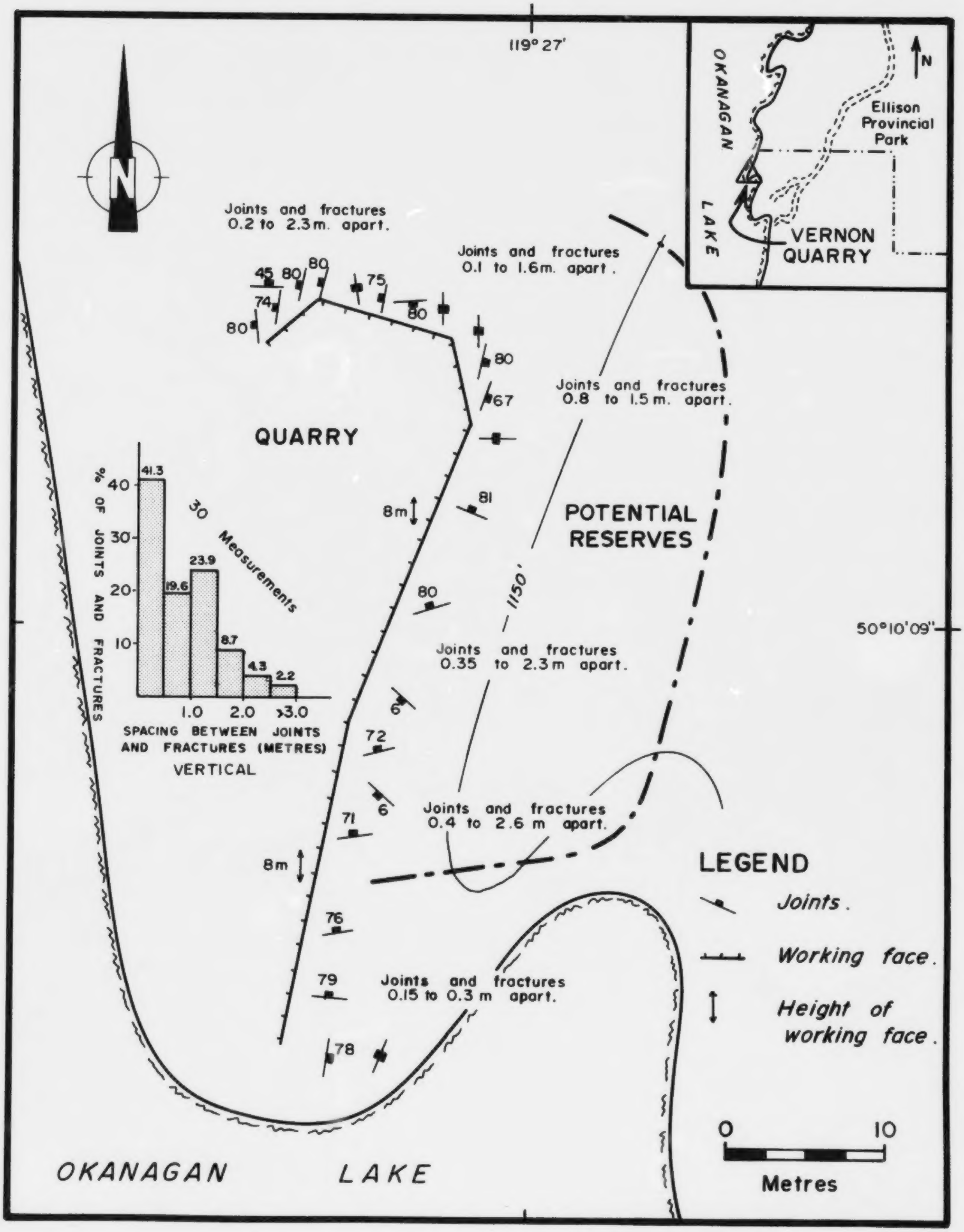

Okanagan Landing
4.5 km
Okanagan Lake Road
Ellison Park
4.4 km
Sunset Subdivision
QUARRY
Gate
N
LEGEND
2 Dyke (Granodiorite).
1 Granite (Pink).
72 Joints; inclined, vertical.
Outline of potential reserves.
Joints 0.1 to 0.4 m. apart along margin of O.C.
70
55
55
Trees
Joints and fractures 0.3 to 1.8 m. apart.
1900'
1950'
2000'
Potential Reserves of Pink Granite
72
48
76
Joints and fractures 0.1 to 1.3 m. apart.
Trees
2
2
-50°12'05"
72
76
Joints 1.7 to 2.4 m. apart.
72
% OF JOINTS AND FRACTURES
50
40
30
20
10
52.0
26.7
21.3
75 Measurements
1.0
2.0
>3.0
SPACING BETWEEN JOINTS AND FRACTURES (METRES)
Joints and fractures 0.1 to 0.3 m. apart along margin of O.C.
2000'
to Okanagan Lake road
Joints 0.1 to 1.0 m.
Quarry
71
58
59
80
37
75
30
Joints 0.4 to 1.4 m. apart.
Quarry Access
0
30
Metres
119°24'10"

Figure 4-8-8. Sunset quarry (82L/3W).



119° 27'
N
OKANAGAN LAKE
N
Ellison Provincial Park
VERNON QUARRY
Joints and fractures 0.2 to 2.3m. apart.
Joints and fractures 0.1 to 1.6m. apart.
45
80
80
75
74
80
80
80
67
QUARRY
Joints and fractures 0.8 to 1.5m. apart.
81
8m
POTENTIAL RESERVES
1150'
80
50°10'09"
Joints and fractures 0.35 to 2.3m apart.
6
72
6
71
Joints and fractures 0.4 to 2.6 m apart.
8m
76
79
Joints and fractures 0.15 to 0.3 m apart.
78
% OF JOINTS AND FRACTURES
40
30
20
10
41.3
19.6
23.9
8.7
4.3
2.2
30 Measurements
1.0
2.0
>3.0
SPACING BETWEEN JOINTS AND FRACTURES (METRES)
VERTICAL
LEGEND
Joints.
Working face.
Height of working face.
0
10
Metres
OKANAGAN LAKE

Figure 4-8-9. Vernon quarry (82L/3W).

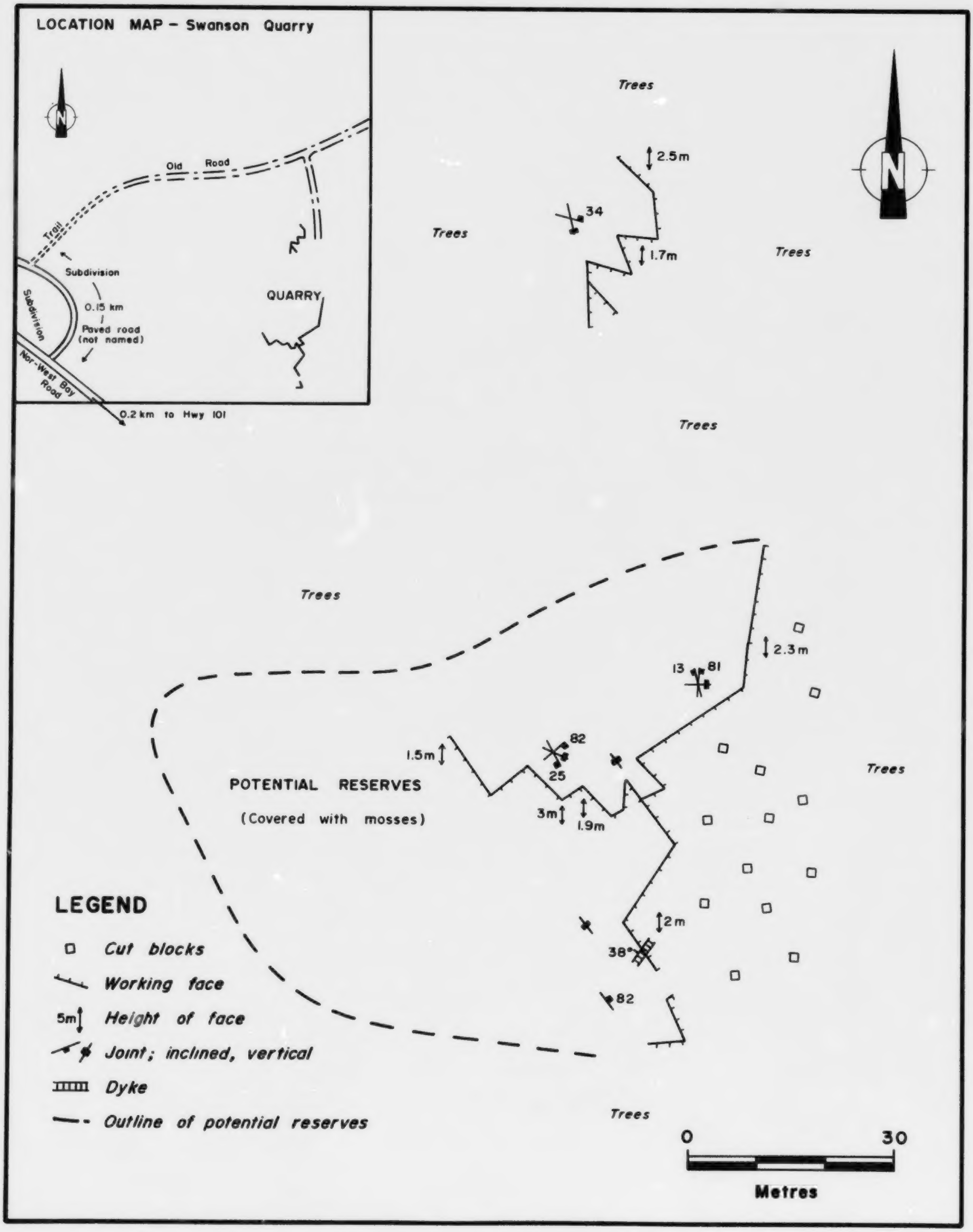

LOCATION MAP - Swanson Quarry
N
Old Road
Trail
Subdivision
0.15 km
Paved road (not named)
Subdivision
Nor-West Bay Road
QUARRY
0.2 km to Hwy 101
Trees
2.5m
34
1.7m
Trees
Trees
N
Trees
Trees
2.3m
13
81
82
25
1.5m
Trees
POTENTIAL RESERVES
(Covered with mosses)
3m
1.9m
2m
38°
82
LEGEND
Cut blocks
Working face
5m
Height of face
Joint; inclined, vertical
Dyke
Outline of potential reserves
Trees
0
30
Metres

Figure 4-8-10. Swanson quarry (92G/5W).

Structure

Three sets of joints are prominent at the site. A vertical set strikes east to southeast; a second set strikes northeast and dips southeast; and a third set strikes south-southeast and dips moderately to the west. Other irregular joints cut the rock with no apparent pattern.

Vertical joints are widely spaced with 70 per cent more than a metre apart. Approximately 50 per cent of vertical joints measured along the exposed working faces are more than 3 metres apart.

Flat-lying joints and fractures are closely spaced with 50 per cent less than a metre apart and 80 per cent less than 2 metres apart.

Reserves

Potential reserves of quarriable stone extend 45 metres west of the abandoned face (Figure 4-8-10) while north, south and east of the quarry heavy second growth forest restricts exposure.

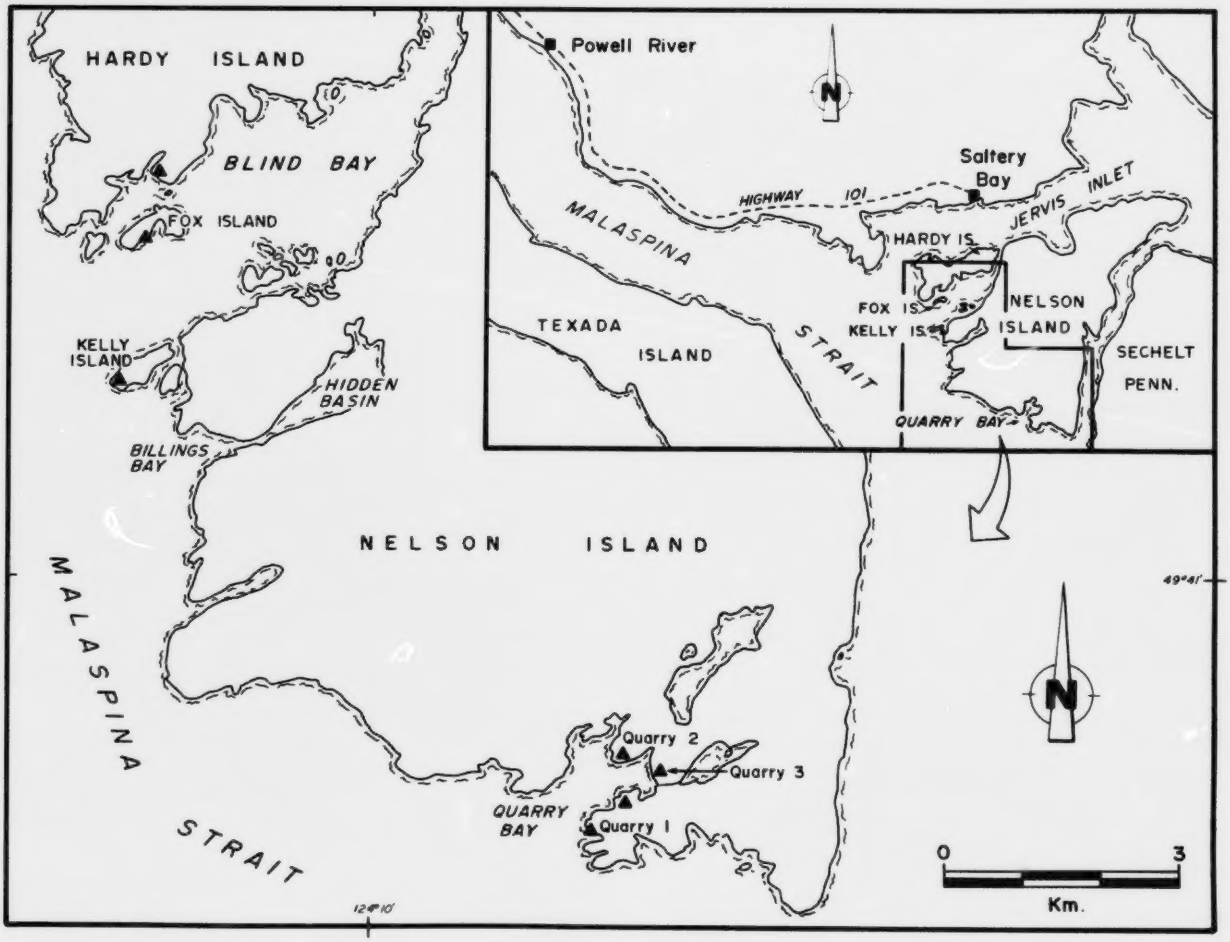
A new housing subdivision is under construction approximately 60 metres west of the quarry. This will almost certainly place limitations on future quarry development.

JERVIS INLET QUARRIES

GRANODIORITE — NELSON ISLAND (QUARRY BAY) (92F/9E)

INTRODUCTION

Four quarries opened in granodiorite of the Coast Plutonic Complex (Roddick *et al.*, 1979) are located on Quarry Bay at the southern tip of Nelson Island (MI 92F-189). They have been operated periodically since the mid-1800s, providing stone for a number of buildings in Vancouver, Nanaimo and Victoria, most notably the Parliament Buildings in Victoria (Parks, 1917).



HARDY ISLAND
BLIND BAY
FOX ISLAND
KELLY ISLAND
HIDDEN BASIN
BILLINGS BAY
NELSON ISLAND
MALASPINA
STRAIT
QUARRY BAY
Quarry 1
Quarry 2
Quarry 3
124°10'
49°41'
N
0
3
Km.
Powell River
Saltery Bay
HIGHWAY 101
JERVIS INLET
MALASPINA STRAIT
TEXADA ISLAND
HARDY IS.
FOX IS.
KELLY IS.
NELSON ISLAND
SECHELT PENN.
QUARRY BAY

Figure 4-8-11. Location map, Jervis Inlet quarries.

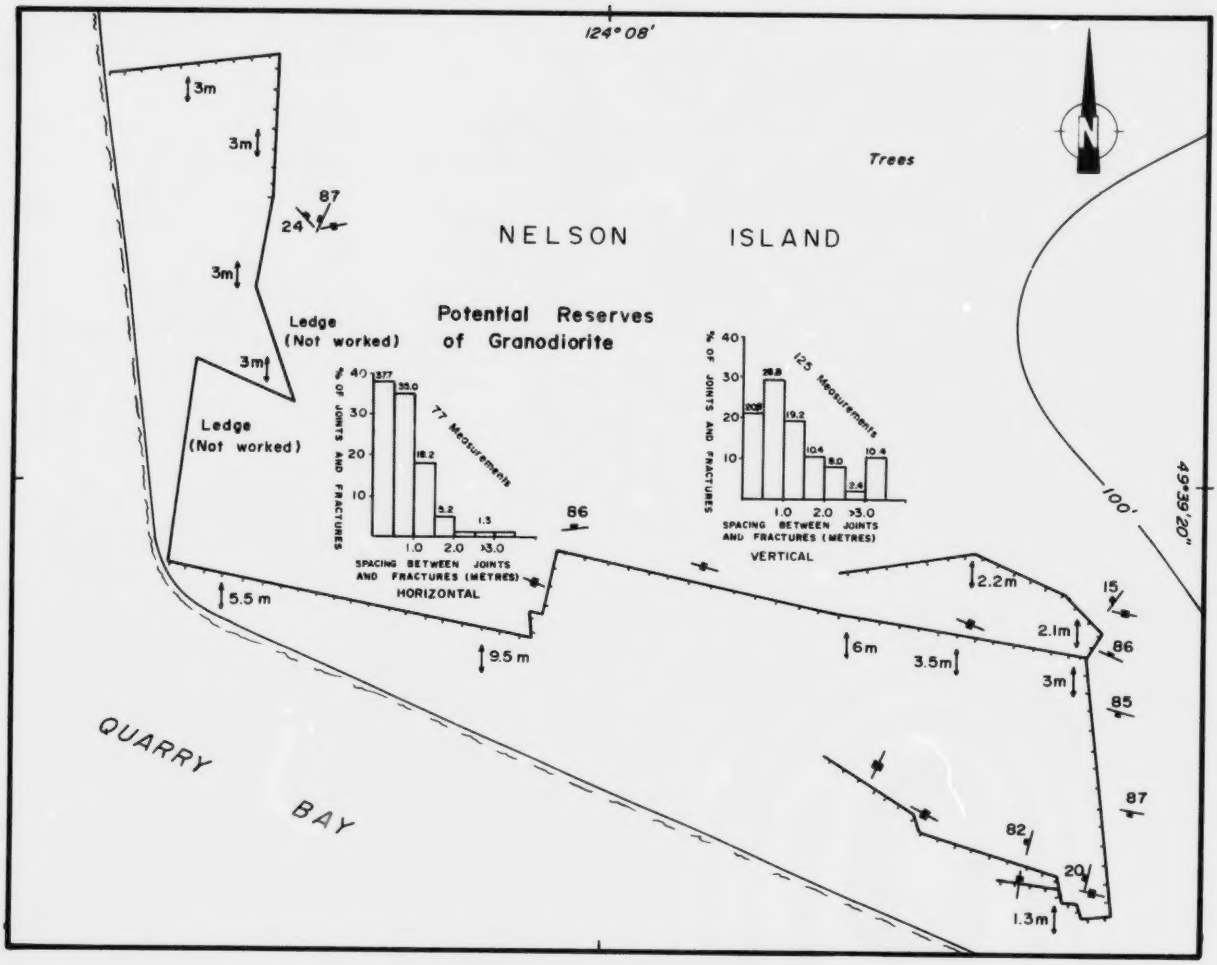

124° 08'
Trees
NELSON ISLAND
Potential Reserves of Granodiorite
Ledge (Not worked)
Ledge (Not worked)
3m
3m
3m
3m
5.5 m
9.5 m
6m
3.5m
2.2m
2.1m
3m
1.3m
87
24
86
15
86
85
87
82
20
100'
49°39'20"
QUARRY BAY
% OF JOINTS AND FRACTURES
40
30
20
10
37.7
35.0
18.2
5.2
1.3
77 Measurements
1.0
2.0
>3.0
SPACING BETWEEN JOINTS AND FRACTURES (METRES)
HORIZONTAL
% OF JOINTS AND FRACTURES
40
30
20
10
20.8
28.8
19.2
10.4
8.0
2.4
10.4
125 Measurements
1.0
2.0
>3.0
SPACING BETWEEN JOINTS AND FRACTURES (METRES)
VERTICAL

Figure 4-8-12. Nelson Island, Quarry 1 (92F/9E).

QUARRY 1

Quarry Development and Sample Description

Quarry 1 (Plate 4-8-11), situated on the north shore of a small inlet near the entrance of Quarry Bay, is approximately 185 metres long (Figure 4-8-12). Worked in benches, it was advanced northeastwards a maximum of 45 metres from the shoreline, with working faces ranging from 3 to 9.5 metres in height.

The granodiorite has a light grey tone, medium texture and a uniform appearance on fresh surfaces. Black blades of biotite (1 to 10 millimetres) and occasional hornblende crystals contrast with the light grey feldspar and quartz matrix.

Scattered knots of mafic minerals (less than 1 per cent by volume), up to 3 centimetres wide by 10 centimetres long, are visible in outcrop. Isolated clusters of pyrite (individual crystals 1 to 2 millimetres in size) are also seen in places.

Structure

Figure 4-8-12 documents orientation and spacing between joints and fractures along the working faces. Almost 80 per cent of the vertical joints and fractures and over 60 per cent of the horizontal joints and fractures are spaced greater than 50 centimetres apart. Of these, 64 per cent of vertical and 27 per cent of horizontal joints and fractures are spaced more than a metre apart.

Reserves

Unworked benches provide additional reserves of stone. Granodiorite exposed north and northeast of the quarry is similar to stone in the working face and offers good reserve potential.

All rock from this quarry tested by Parks (1917) meets ASTM standards for granite building stone (Table 4-8-2).

QUARRY 2

Quarry Development and Sample Description

Quarry 2 (Plate 4-8-12) is located on a point at the north end of Quarry Bay (Figure 4-8-11). It consists of three working faces developed along the south and southeast shores of the point. The southern face, approximately 90 metres long and 2.8 to 10 metres high, has been advanced 15 metres from the shore. Face 2 is approximately 75 metres long by 3 to 4 metres high. Face 3, although not continuous, is approximately 45 metres long and 2 to 4 metres high.

The stone is similar in appearance to granodiorite in Quarry 1. Mafic minerals (biotite and hornblende) give it an attractive salt-and-pepper look, complementing the light grey feldspar and quartz matrix. The stone is medium grained with a few scattered black knots (up to 7 by 15 centimetres in size); rare occurrences of pyrite are localized along prominent joints.

Structure

The orientation of joints and fractures is described in Figure 4-8-13. This figure illustrates the spacing between joints and fractures measured along the abandoned working faces. Almost 90 per cent of vertical joints and fractures and 70 per cent of horizontal fractures are spaced more than 50 centimetres apart. Approximately 70 per cent of all joints and fractures are more than a metre apart.

Reserves

Potential reserves of quarriable stone lie immediately northeast of Face 1 and northwest of Faces 2 and 3 (Figure 4-8-13). This stone is similar to granodiorite examined along the working faces and could be quarried by advancing the existing workings.

All rock tested by Parks (1917) meets ASTM standards for granite building stone (Table 4-8-2).

QUARRY 3

Quarry Development and Sample Description

Quarry 3 (Plate 4-8-13), the largest of the quarries, lies along a ridge on the east shore of Quarry Bay (Figure 4-8-11). An opening, approximately 40 metres long and up to 6 metres high, parallels the shoreline (Face 1, Figure 4-8-14). More extensive openings developed up the hill are designated Faces 2 to 4.

Face 2 is approximately 115 metres long and up to 18 metres high. Face 3, above and to the northeast of Face 2, is approximately 60 metres long with a working face 18 metres high. Face 4, located above and to the northeast of Face 3, is approximately 80 metres long and has a working face 20 metres high.

Stone from the quarry is similar to the granodiorite examined at Quarries 1 and 2. It has a light grey tone and a medium-grained texture, with biotite blades (1 to 10 millimetres) and minor hornblende contrasting with a lighter feldspar and quartz matrix. Black knots and dark inclusions comprise less than 1 per cent of the total volume.

Rock sampled by Parks (1917) meets ASTM standards for granite building stone (Table 4-8-2).

Structure

Joints measured along the four working faces are illustrated in Figure 4-8-14. Greater than 80 per cent of vertical joints and fractures and over 74 per cent of horizontal joints are spaced more than 50 centimetres apart. Some 60 per cent of all structures are spaced wider than 100 centimetres.

Reserves

Additional reserves of building stone are available along all four working faces. The faces could be advanced northeast, in a series of benches up the ridge (Figure 4-8-14).

QUARRY 4

Quarry 4 (Figure 4-8-11), the smallest of the four, was located but not investigated. Cottages built on the old workings prevent access to the site.

GRANODIORITE — HARDY ISLAND
(92F/9E)

INTRODUCTION

Two abandoned quarries on the southwest shore of Hardy Island (MI 92F-425) provided stone for breakwaters in Vancouver and Victoria (Parks, 1917) (Plate 4-8-14). The quarries, opened in granodiorite of the Coast Plutonic Complex (Roddick *et al.*, 1979), have good potential for further development.

LOWER QUARRY

Quarry Development and Sample Description

The lower quarry (Plate 4-8-15), located on the northwest shore of a small inlet off Blind Bay (Figure 4-8-11), has an opening approximately 100 metres long. Worked faces, ranging from 2 to 23 metres high, have been advanced northeast in benches from the shoreline (Figure 4-8-15).

The rock, similar in appearance to the granodiorite at Quarry Bay, weathers grey to black. It is medium to coarse grained with a uniform appearance and a light grey tone on fresh surfaces. Minerals seen in hand specimen include feldspar, quartz, biotite and hornblende. Black knots, up to 30 centimetres across, are common and pyrite and chalcopyrite are frequently noted.

Physical Tests

Physical tests carried out by Parks (1917) indicate the stone does not meet ASTM standards for modulus of rupture for granite (Table 4-8-2).

Structure

Orientation and spacing between joints and fractures are illustrated in Figure 4-8-15. Over 87 per cent of steeply dipping fractures are spaced more than 50 centimetres apart and 72 per cent over a metre apart. Almost 30 per cent of fractures are spaced more than 3 metres apart.

Flat-lying joints and fractures are well developed with more than 81 per cent spaced 50 centimetres apart and 65 per cent spaced a metre apart. A relatively large proportion, 22 per cent, are spaced more than 3 metres apart.

One large cut block on site measured 9.3 by 6 by 5 metres, an indication of the size of blocks potentially available.

UPPER QUARRY

Quarry Development and Sample Description

Approximately 35 metres west of the lower quarry a second opening, 95 metres wide by 5 to 18 metres high (Figure 4-8-15), has been advanced north along a northeast set of steeply dipping joints.

The stone, similar to the lower quarry, is light grey with a uniform appearance on fresh surfaces. Blades of biotite and occasional hornblende crystals contrast with a matrix of light grey feldspar and quartz. As at the lower quarry, large black knots (up to 30 centimetres across) are common and pyrite is common on joint planes. Exposed surfaces weather grey to black.

Structure

Prominent northeasterly striking joints dip south 75 degrees to vertical with more northerly striking joints dipping east 18 to 30 degrees. Irregular northwest-striking joints dip west at 16 degrees. Joint and fracture spacing, similar to the lower quarry, is illustrated in Figure 4-8-15.

RESERVES

Reserves of quarriable stone remain in undeveloped benches at both sites extending north-northeast from abandoned faces (Figure 4-8-15).

GRANODIORITE — KELLY ISLAND
(92F/9E)

Introduction

Five quarries (MI 92F-196) opened in granodiorite of the Coast Plutonic Complex (Roddick *et al.*, 1979) on the southwest end of Kelly Island (formerly Granite Island) were developed around the

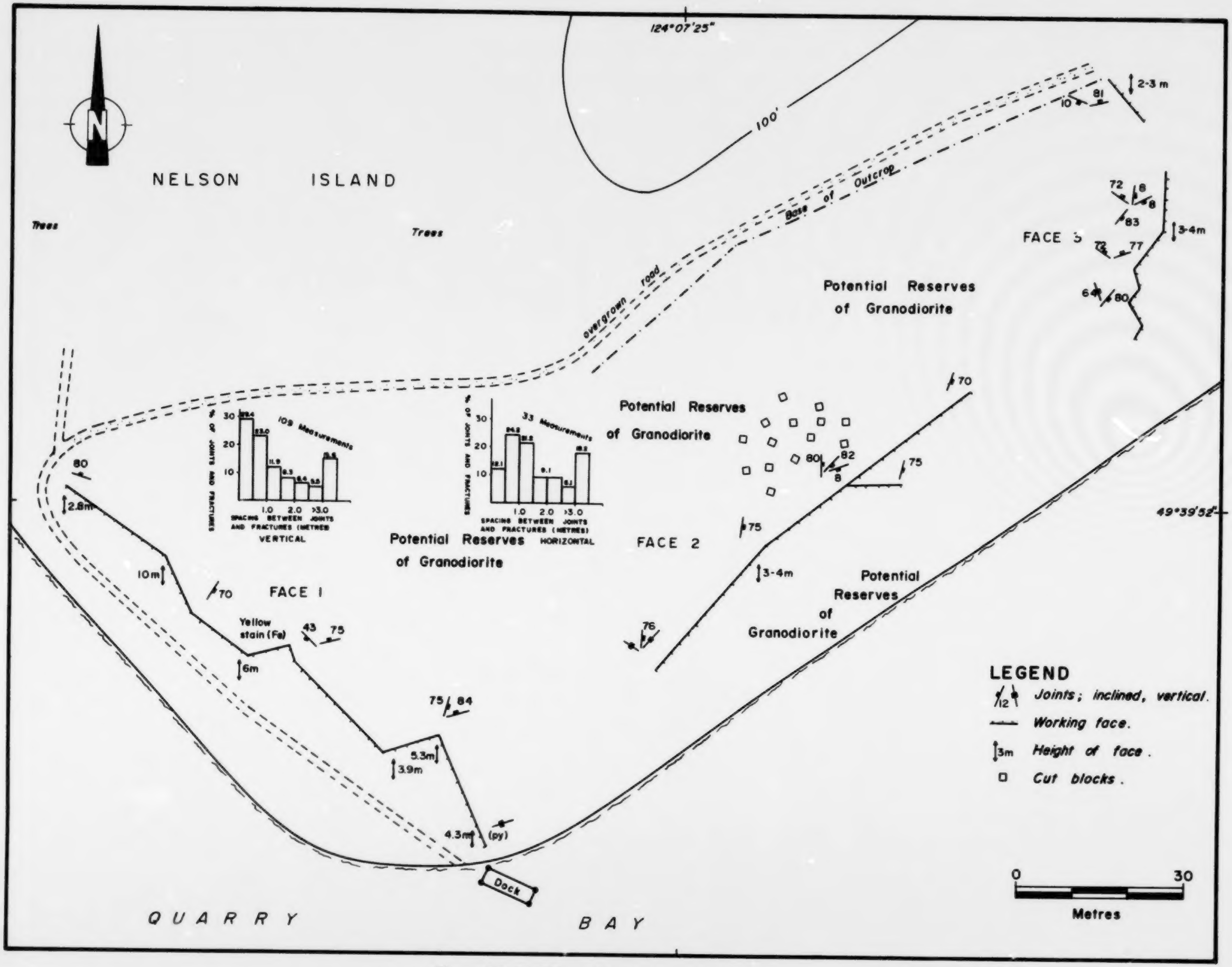

124°07'25"
49°39'52"
N
NELSON ISLAND
Trees
Trees
100'
Base of Outcrop
overgrown road
FACE 1
FACE 2
FACE 3
Potential Reserves of Granodiorite
Potential Reserves of Granodiorite
Potential Reserves of Granodiorite
Potential Reserves of Granodiorite
2-3 m
10
81
72
8
8
83
3-4m
72
77
64
80
70
75
80
82
8
75
3-4m
76
80
2.8m
10m
70
Yellow stain (Fe)
43
75
6m
75
84
5.3m
3.9m
4.3m
(py)
Dock
QUARRY BAY
109 Measurements
% OF JOINTS AND FRACTURES
30
20
10
28.4
23.0
11.9
8.3
6.4
5.5
15.6
1.0
2.0
>3.0
SPACING BETWEEN JOINTS AND FRACTURES (METRES)
VERTICAL
33 Measurements
% OF JOINTS AND FRACTURES
30
20
10
12.1
24.2
21.2
9.1
6.1
18.2
1.0
2.0
>3.0
SPACING BETWEEN JOINTS AND FRACTURES (METRES)
HORIZONTAL
LEGEND
12
Joints; inclined, vertical.
Working face.
3m
Height of face.
Cut blocks.
0
30
Metres

Figure 4-8-13. Nelson Island, Quarry 2 (92F/9E).

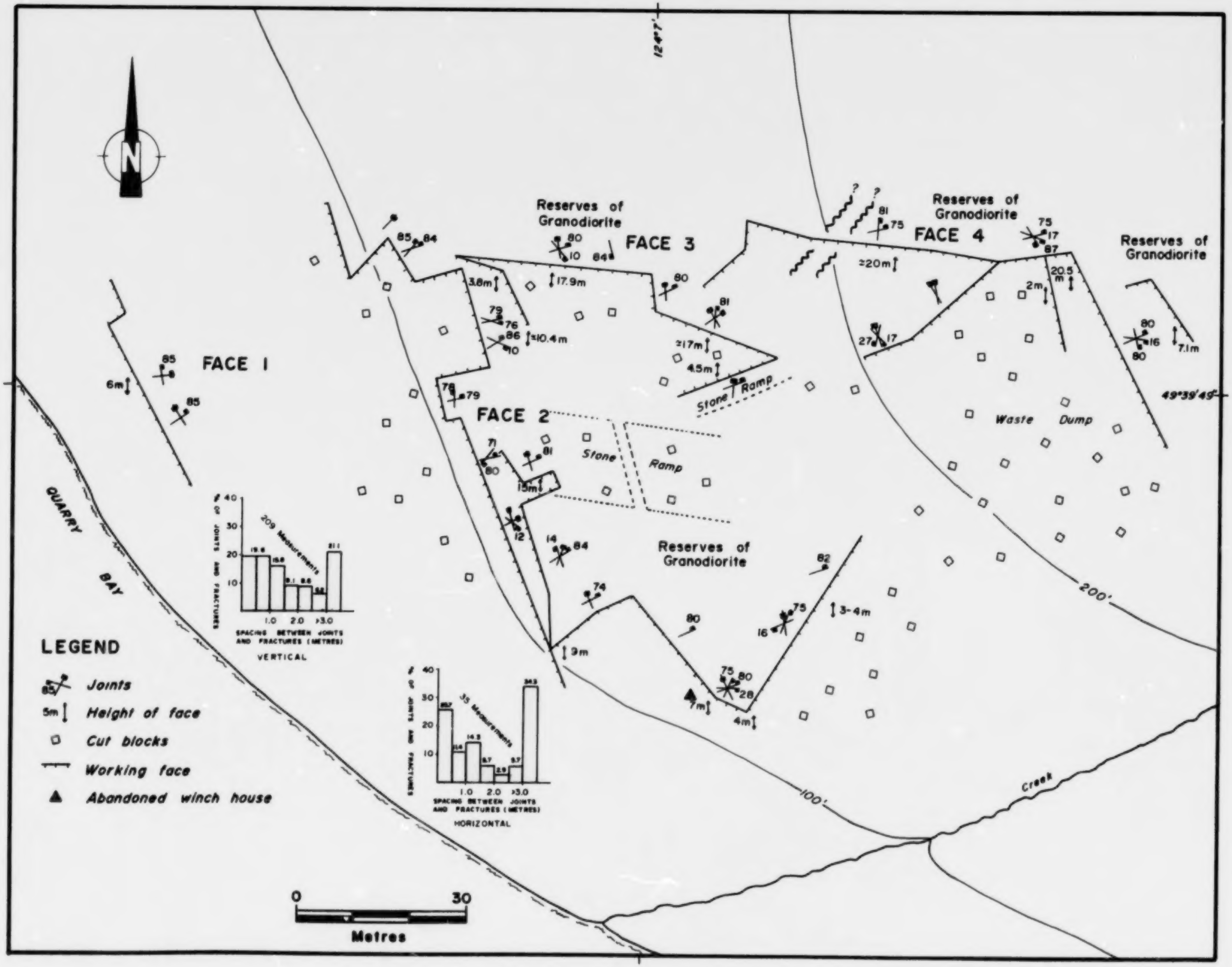

N
12°47'
49°39'45"
Reserves of Granodiorite
FACE 1
FACE 2
FACE 3
FACE 4
Stone
Ramp
Waste Dump
QUARRY BAY
Creek
200'
100'
6m
3.8m
17.9m
≈10.4m
≈17m
4.5m
15m
9m
≈20m
20.5 m
2m
7.1m
3-4m
7m
4m
85
84
80
10
79
76
86
78
71
81
12
14
74
82
75
16
28
27
17
87
% OF JOINTS AND FRACTURES
40
30
20
10
209 Measurements
19.6
15.8
9.1
8.6
6.2
21.1
1.0
2.0
>3.0
SPACING BETWEEN JOINTS AND FRACTURES (METRES)
VERTICAL
35 Measurements
25.7
11.4
14.3
5.7
2.9
5.7
34.3
HORIZONTAL
LEGEND
Joints
Height of face
Cut blocks
Working face
Abandoned winch house
0
30
Metres

Figure 4-8-14. Nelson Island, Quarry 3 (92F/9E).

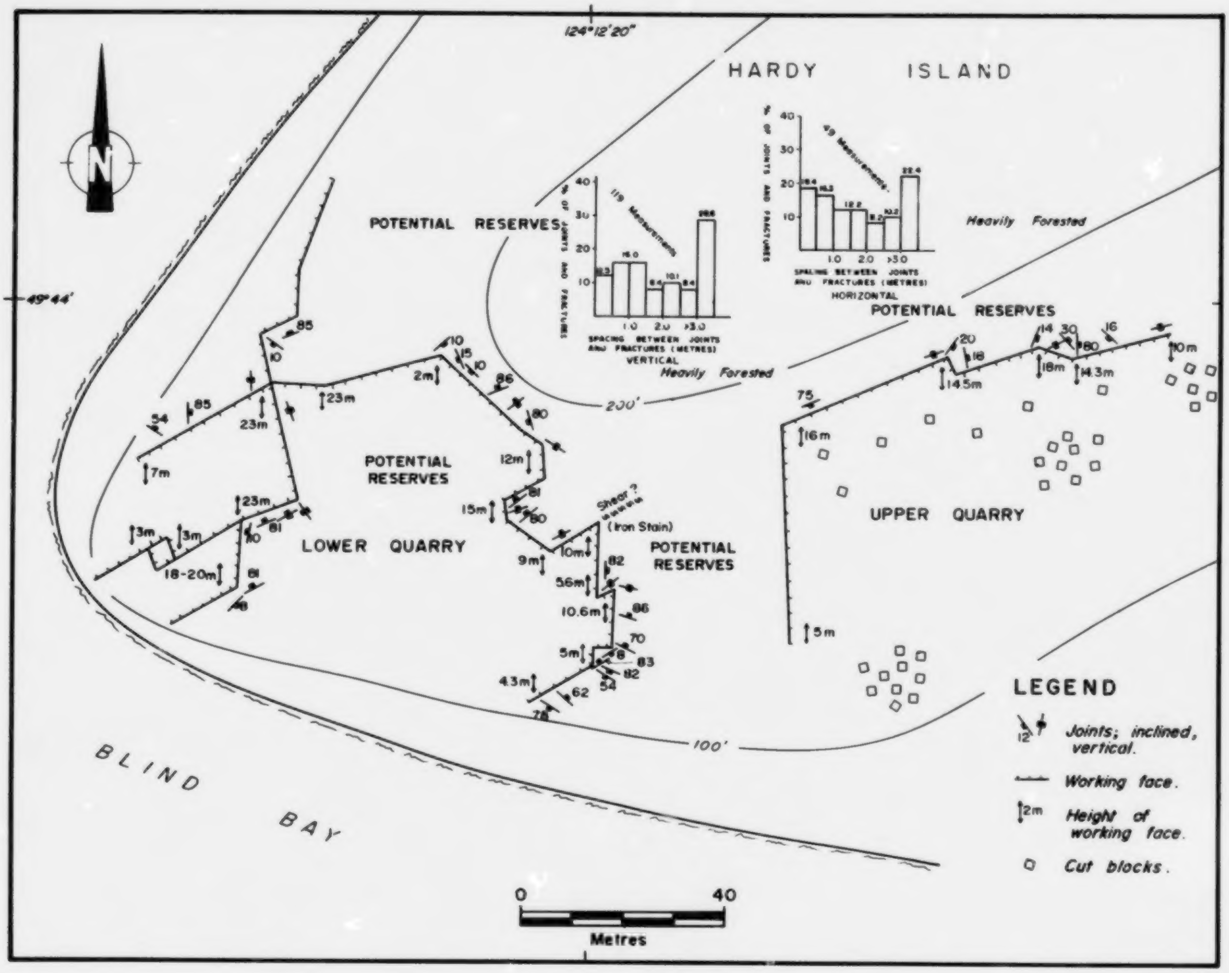

124°12'20"
49°44'
N
HARDY ISLAND
POTENTIAL RESERVES
POTENTIAL RESERVES
POTENTIAL RESERVES
POTENTIAL RESERVES
LOWER QUARRY
UPPER QUARRY
Heavily Forested
Heavily Forested
200'
100'
Shear ?
(Iron Stain)
BLIND BAY
119 Measurements
# of joints and fractures
Spacing between joints and fractures (metres)
VERTICAL
49 Measurements
HORIZONTAL
1.0
2.0
>3.0
LEGEND
Joints; inclined, vertical.
Working face.
Height of working face.
Cut blocks.
0
40
Metres

Figure 4-8-15. Hardy Island quarries (92F/9E).

turn of the century (Parks, 1917; Figure 4-8-11 and Plate 4-8-16). Recent examination of the sites outlined reserves of quarriable granodiorite.

Sample Description

Medium-grained granodiorite from all five quarries is similar in appearance but slightly darker than stone from Nelson and Hardy Islands (Parks, 1917), having more biotite. Patches of pyrite less than 1 centimetre in size and a few black knots (estimated to be less than 0.5 per cent of volume) are visible on the quarry face. The stone, used to construct the Victoria Harbour seawall, has an attractive fresh appearance after over a half a century of exposure.

Physical tests by Parks (Table 4-8-2) indicate the stone meets ASTM standards for granite building stone.

Quarry Development

Quarry 1

Quarry 1 is located 15 metres north of the shoreline on the southwest coast of the island (Figure 4-8-16). Its opening, 40 metres wide by 11 metres high, was developed along vertically dipping northwest-trending joints and south-dipping northeast-striking joints.

Quarry 2

Quarry 2 (Plate 4-8-17), the largest of the four sites, lies 35 metres northeast of Quarry 1. Developed along a prominent ridge, it is approximately 110 metres long and has a working face 12 metres high. Three sets of near-vertical joints strike northeast, east and southeast. Flat joints strike south-southeast and dip 8 to 10 degrees west (Figure 4-8-16).

Vertical joints and fractures measured along the face are widely spaced with over 91 per cent greater than 50 centimetres apart and nearly 60 per cent spaced over 100 centimetres apart (Figure 4-8-16). Horizontal joints averaged more than a metre apart.

Quarry 3

Quarry 3, approximately 55 metres long with benches 4 to 6 metres high, is 85 metres west of Quarry 1.

Four sets of prominent steeply dipping joints are recognized, with strikes ranging from northeast to south. Flat joints strike north-northeast and dip 10 degrees east. More than 94 per cent of joints and fractures are spaced greater than 50 centimetres apart with 77 per cent spaced over 100 centimetres apart and 16 per cent over 300 centimetres apart (Figure 4-8-16).

Quarries 4 and 5

Quarries 4 and 5, approximately 30 metres long by 3 to 5.2 metres high and 25 metres long by 4 metres high respectively, are 105 metres northwest of Quarry 2 on the northwest shore of Kelly Island.

The attitudes of three steeply dipping joint sets are: northerly, dipping west; northeasterly, dipping south; and southeasterly, dipping north. The attitudes of flat-dipping joints are variable. Over 91 per cent of joints and fractures are spaced greater than 50 centimetres apart and over 67 per cent are spaced wider than 100 centimetres. Flat joints are spaced more than a metre apart (Figure 4-8-16).

Reserves

Reserves of quarriable stone extend north-northeast of Quarries 1 and 2, north-northwest of Quarry 3 and south-southeast of Quarries 4 and 5 (Figure 4-8-16). Granodiorite north of Quarry 2 is more intensely fractured than stone at the quarry itself, however measurements indicate 75 per cent of potential reserves could be cut into 50-centimetre blocks.

GRANODIORITE — FOX ISLAND
(92F/9E)

Introduction

Granodiorite of the Coast Plutonic Complex (Roddick *et al.*, 1979) was extracted from a small quarry (MI 92F-378) on the south shore of Fox Island around the turn of the century (Figure 4-8-11 and Plate 4-8-18). Examination of exposures north and west of the quarry indicates potential reserves of dimension stone.

Sample Description

The granodiorite is visibly lighter in appearance than Kelly Island stone and slightly coarser (Parks, 1917). It is medium grained, light grey in colour on fresh surfaces and weathers grey to black. Black knots of mafic minerals (biotite, hornblende) up to 10 by 20 centimetres are infrequent (less than 0.5 per cent of total volume) and small pyrite crystals (less than 1 millimetre in size) occur in isolated patches.

While no buildings constructed from the stone were examined, exposed quarry walls appear fresh.

Quarry Development

An opening approximately 30 metres long by 3.5 to 11 metres high was developed along the shore of Fox Island (Figure 4-8-17). A second small opening, 10 metres to the northwest, measures 10 metres long by up to 1.6 metres high.

Three sets of steeply dipping joints are recognized: east-northeast dipping north; east-northeast dipping south; and south-southeast dipping east. Two low-angle joints measured in the quarries strike 85 degrees dipping 10 degrees south and 135 degrees dipping 12 degrees southwest (Figure 4-8-17).

Spacing between joints and fractures, in the quarries and adjacent outcrops, indicates that large blocks are available (Figure 4-8-17). Over 90 per cent of all joints and fractures measured were greater than 50 centimetres apart, almost 80 per cent are spaced more than 100 centimetres apart and a significant proportion are spaced wider than 300 centimetres apart.

Reserves

Potential reserves of dimension stone extend north and west of the larger quarry, parallel to the shoreline, for at least 30 metres. Outcrops are covered by vegetation but limited examination of the rock suggests it is similar to the quarry exposures. Dense second growth forest cover prevented detailed examination north, west and east of the small quarry.

SUMMARY — JERVIS INLET QUARRIES

Dimension stone quarries on Nelson, Hardy, Kelly and Fox Islands have operated sporadically since the nineteenth century, supplying large volumes of stone to markets in the Lower Mainland and Vancouver Island. Examination of each site during July 1986 revealed:

(1) Subtle differences in texture and colour exist between granodiorite from each of the islands. Specifically, stone from Fox and Hardy Islands is slightly coarser than Nelson or Kelly Island granodiorites. Kelly Island granodiorite is darker than stone from the other islands.

(2) Joint and fracture density is highest at the three Nelson Island quarries with approximately 30 to 40 per cent spaced less than 50 centimetres apart. Joint and fracture density on Hardy, Kelly and Fox Islands is not as intense with approximately 10 to 20 per cent spaced less than 50 centimetres apart.

(3) Black knots and minor amounts of sulphides are more frequently seen in Hardy Island quarries, but their total volume is still small.

(4) Quarries 2 and 3 on Nelson Island and the quarries on Hardy and Kelly Islands have large potential reserves.

Three sites must remain available for development if British Columbia wishes to preserve a major source of Jervis Inlet granodiorite. These are Quarry 3 on Nelson Island and the quarries on Hardy and Kelly Islands.

MARBLE — NOOTKA SOUND

HISNIT INLET QUARRY
(92E/15E)

Introduction

A small quarry (MI 92E-020), opened in crystalline limestone of Middle to Upper Triassic Quatsino Formation (Muller *et al.*, 1981), operated briefly on Hisnit Inlet from 1908 to 1909 (Plate 4-8-19). Examination of the quarry and surrounding area indicates limited potential for further development.

Sample Description

Marble examined in the quarry has an attractive white to light grey colour, is medium grained and similar in appearance to crystalline limestone from Marblehead. Parks (1917) determined the marble is 95.62 to 97.86 per cent calcium carbonate equivalent and physical tests indicate the rock conforms to modern ASTM standards for marble building stone exterior (Table 4-8-2).

Quarry Development and Structure

The quarry, developed in a poorly exposed outcrop 16.5 metres east of the shoreline, is rectangular in shape with sides 14.6 metres long by 12.1 metres wide by a maximum 6 metres high (Figure 4-8-18).

Remnant beds are thought to strike 60 to 80 degrees although attitudes are difficult to determine. Basalt dykes cut the marble along the north and east walls of the quarry; flooding prevented close examination of the south and east walls.

According to Parks, channellers removed slabs of marble "5 feet by 5 or even 6 feet, probably from blocks obtained at the bottom of the quarry". This is the best estimation of the size of blocks available as outcrop is covered by water in the quarry and by heavy second growth forest elsewhere.

Reserves

Basalt dykes occupy 55 per cent of the north wall and 23 per cent of the east wall of the quarry (Figure 4-8-18). Heavy forest growth

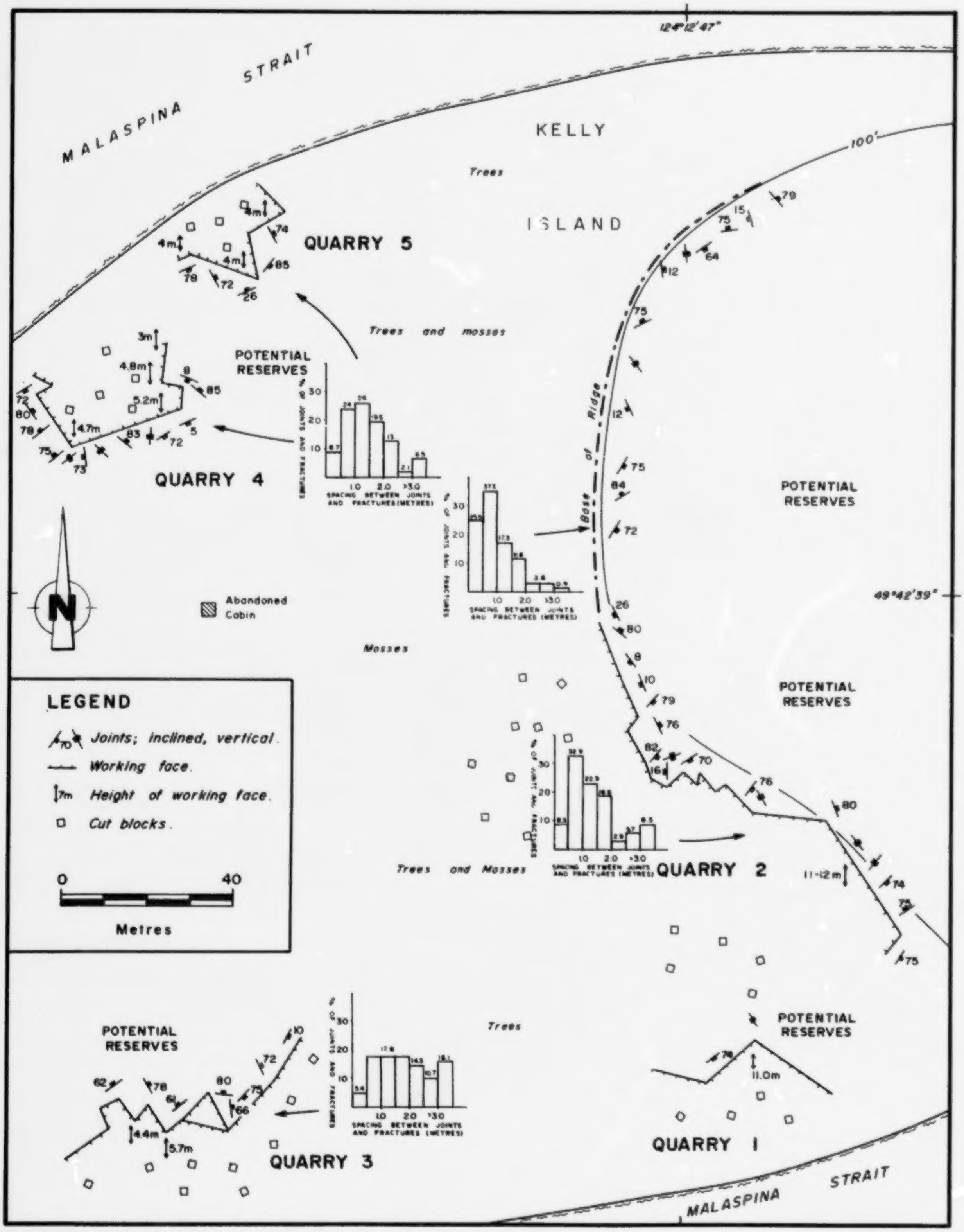

124°12'47"
MALASPINA STRAIT
KELLY
ISLAND
Trees
100'
QUARRY 5
4m
4m
4m
74
85
78
72
26
Trees and mosses
POTENTIAL RESERVES
3m
4.8m
5.2m
4.7m
8
85
72
80
78
75
73
83
72
5
QUARRY 4
% OF JOINTS AND FRACTURES
SPACING BETWEEN JOINTS AND FRACTURES (METRES)
1.0
2.0
>3.0
10
20
30
Base of Ridge
79
15
75
64
12
75
12
75
84
72
26
80
8
10
79
76
82
16
70
76
80
74
75
75
11-12m
POTENTIAL RESERVES
49°42'39"
Abandoned Cabin
Mosses
LEGEND
Joints; inclined, vertical.
Working face.
Height of working face.
Cut blocks.
0
40
Metres
Trees and Mosses
QUARRY 2
POTENTIAL RESERVES
Trees
POTENTIAL RESERVES
62
78
61
80
72
10
75
66
4.4m
5.7m
QUARRY 3
74
11.0m
QUARRY 1
MALASPINA STRAIT

Figure 4-8-16. Kelly Island quarries (92F/9E).

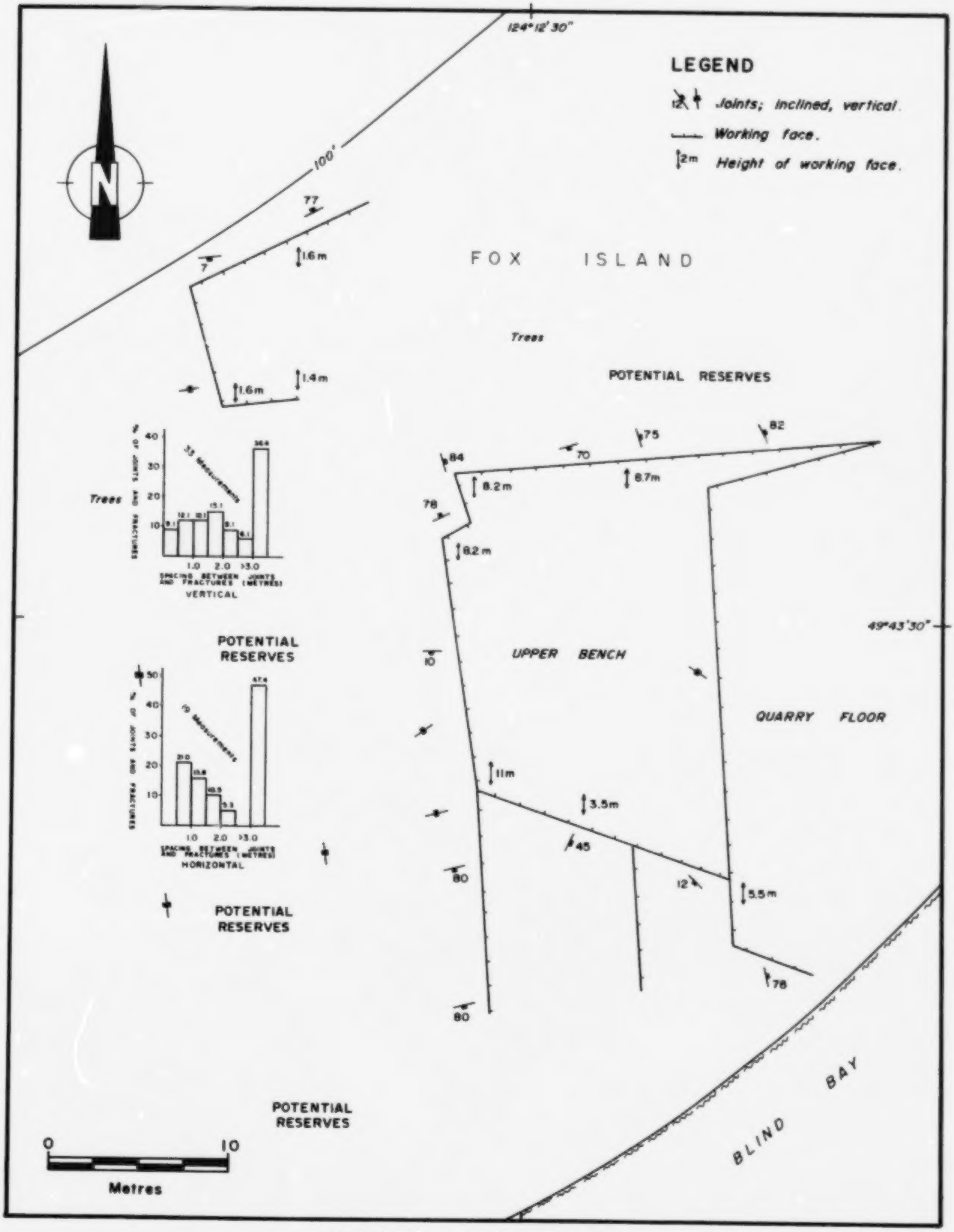

124°12'30"
LEGEND
12 Joints; inclined, vertical.
Working face.
2m Height of working face.
N
100'
77
7
1.6m
FOX ISLAND
Trees
1.6m
1.4m
POTENTIAL RESERVES
75
82
84
70
8.2m
8.7m
78
8.2m
Trees
% OF JOINTS AND FRACTURES
40
30
20
10
33 Measurements
9.1
12.1
12.1
15.1
9.1
6.1
36.4
1.0
2.0
>3.0
SPACING BETWEEN JOINTS AND FRACTURES (METRES)
VERTICAL
POTENTIAL RESERVES
10
UPPER BENCH
49°43'30"
QUARRY FLOOR
% OF JOINTS AND FRACTURES
50
40
30
20
10
19 Measurements
21.0
15.8
10.5
5.3
47.4
1.0
2.0
>3.0
SPACING BETWEEN JOINTS AND FRACTURES (METRES)
HORIZONTAL
11m
3.5m
45
80
12
5.5m
POTENTIAL RESERVES
78
80
POTENTIAL RESERVES
0
10
Metres
BLIND BAY

Figure 4-8-17. Fox Island quarry (92F/9E).

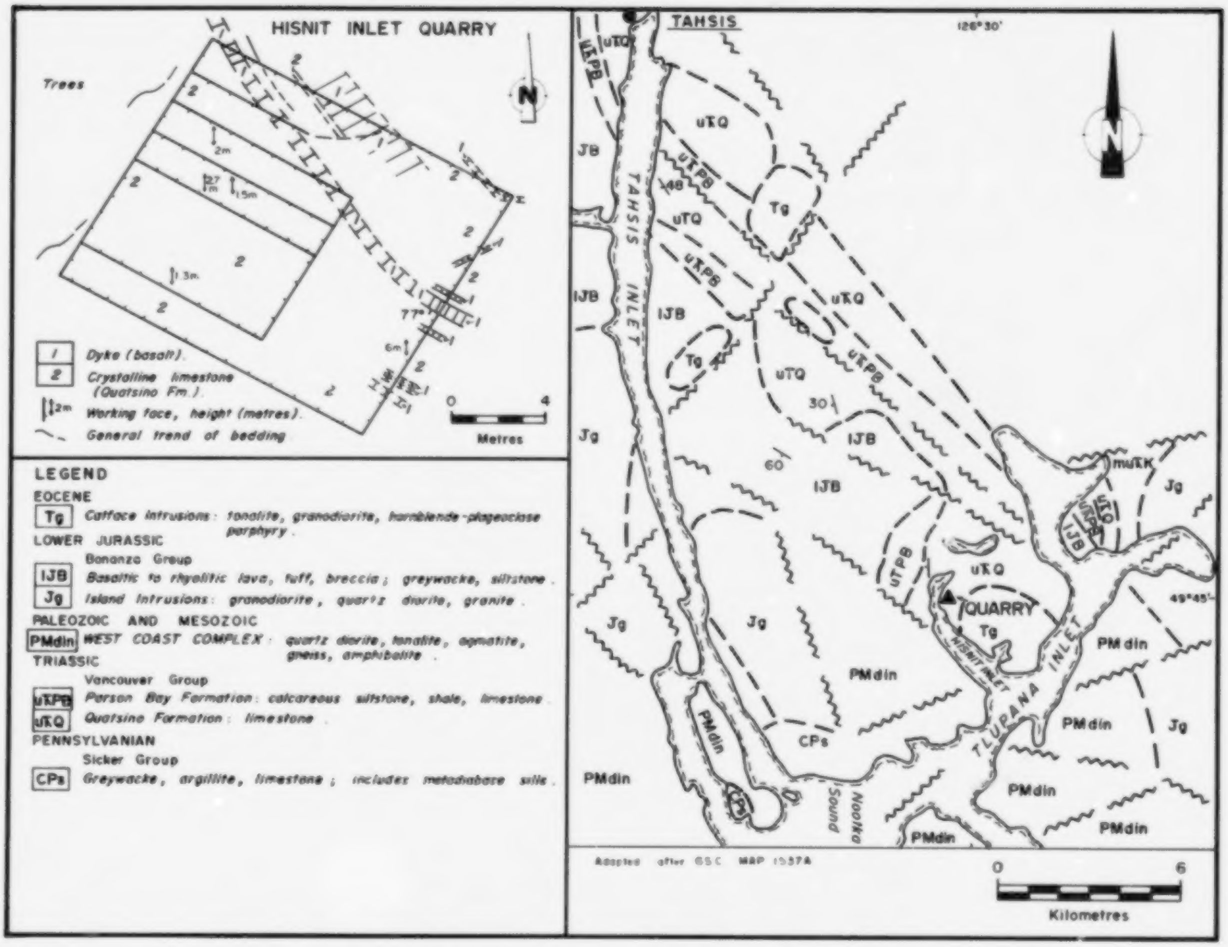

HISNIT INLET QUARRY
Trees
N
2m
1.5m
1.3m
6m
77°
27
1
2
Dyke (basalt).
Crystalline limestone (Quatsino Fm.).
2m Working face, height (metres).
General trend of bedding
0
4
Metres
LEGEND
EOCENE
Tg Catface Intrusions: tonalite, granodiorite, hornblende-plagioclase porphyry.
LOWER JURASSIC
Bonanza Group
lJB Basaltic to rhyolitic lava, tuff, breccia; greywacke, siltstone.
Jg Island Intrusions: granodiorite, quartz diorite, granite.
PALEOZOIC AND MESOZOIC
PMdln WEST COAST COMPLEX: quartz diorite, tonalite, agmatite, gneiss, amphibolite.
TRIASSIC
Vancouver Group
uTrPB Parson Bay Formation: calcareous siltstone, shale, limestone.
uTrQ Quatsino Formation: limestone.
PENNSYLVANIAN
Sicker Group
CPs Greywacke, argillite, limestone; includes metadiabase sills.
TAHSIS
126°30'
TAHSIS INLET
uTrQ
uTrPB
lJB
JB
Jg
Tg
PMdln
CPs
muTrK
QUARRY
HISNIT INLET
TLUPANA INLET
Nootka Sound
49°45'
48
30
60
Adapted after GSC MAP 1537A
0
6
Kilometres

Figure 4-8-18. Nootka Sound, Hisnit Inlet quarry (92E/15E).

prevented examination of outcrops near the quarry and its potential cannot be documented by surface examination.

There is good potential for quarriable reserves elsewhere in the Quatsino limestone between Tahsis and Tlupana Inlets, but a grassroots exploration program would be required to identify specific prospects.

ACKNOWLEDGMENTS

The author would like to acknowledge Z.D. Hora for suggesting the study and reviewing the paper. The British Columbia Ministry of Transportation and Highways (Geotechnical and Materials Branch) carried out physical tests on Ymir and Beaverdell samples. David Hannay provided capable and cheerful field assistance throughout the project.

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Plate 4-8-1. Northwest corner of Ymir quarry (92F/6E). Note 1.7 × 1.6 × 0.55-metre blocks left on site (foreground).

Plate 4-8-2. Three Mile Point quarry (82F/11W). Site 1. Note reserves of granodiorite and horizontal joints.

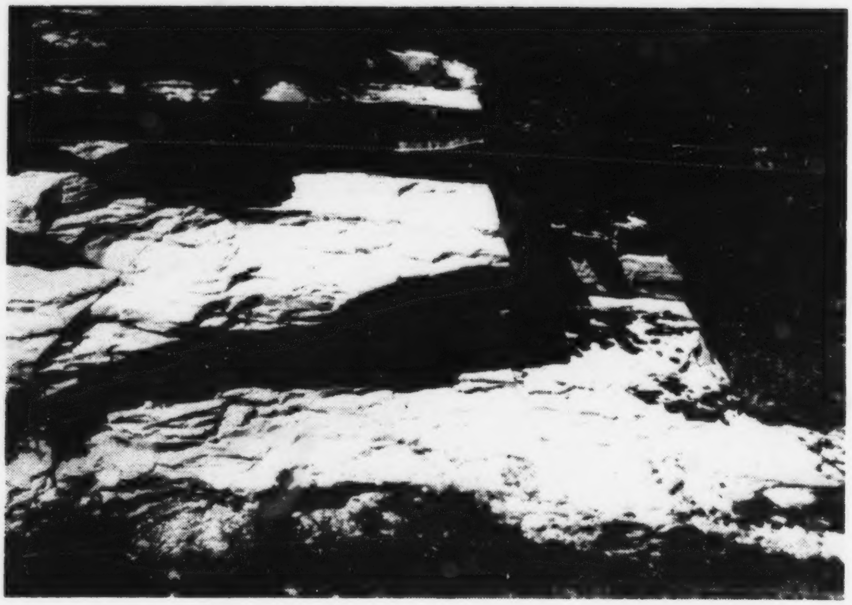

Plate 4-8-3. Marblehead (82K/7W). Quarry 1. Reserves of marble 3.1 kilometres north of Meadow Creek bridge, Highway 31.

Plate 4-8-4. Marblehead (82K/7W). Quarry 3. South portal (approximately 10 metres in height).

Plate 4-8-5. Reserves of marble immediately north of the Kaslo quarry (82F/15W). Joints are spaced 2 to 3 metres apart.

Plate 4-8-6. Beaverdell quarry (82E/6E). Looking northeast with quarry in foreground and potential reserves of granite exposed along ridge.

Plate 4-8-7. Sunset quarry (82L/3W). Looking northeast of quarry working face.

Plate 4-8-8. Sunset quarry (82L/3W). Reserves of granite along a northeast-trending ridge approximately 40 metres northeast of worked face.

Plate 4-8-9. Vernon quarry (82L/3W). Note steeply dipping vertical joints. Looking north.

Plate 4-8-10. Swanson quarry, Sechelt (92G/5W). Abandoned working face — 2 metres high. Looking northwest.

Plate 4-8-11. Nelson Island, Quarry Bay (92F/9E). Looking north at abandoned face of Quarry 1.

Plate 4-8-12. Nelson Island, Quarry Bay (92F/9E). Looking north at face of Quarry 2.

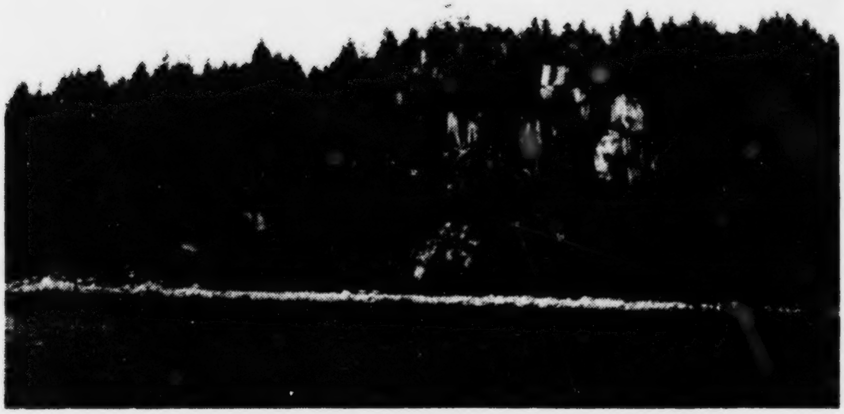

Plate 4-8-13. Nelson Island, Quarry Bay (92F/9E). Looking northwest at abandoned faces of Quarry 3. Top bench is approximately 61 metres above sea level.

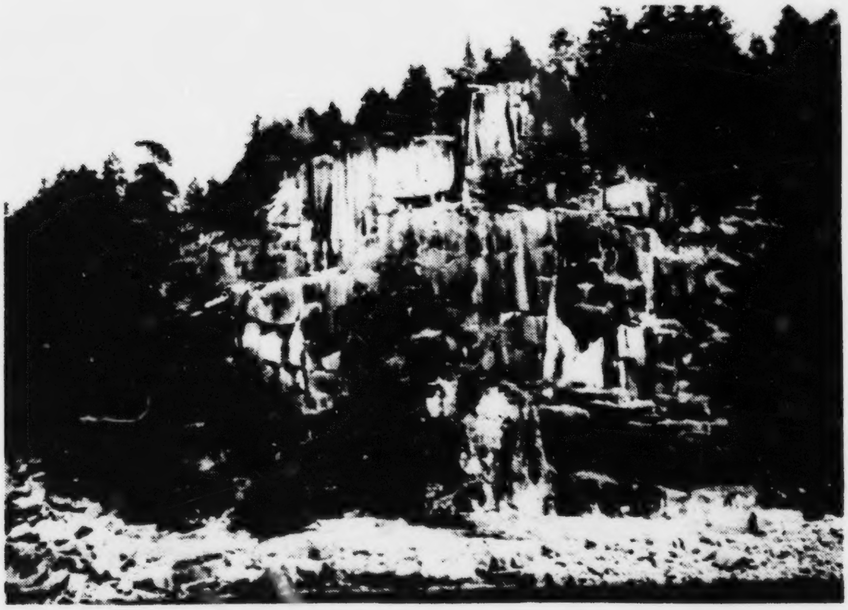

Plate 4-8-14. Hardy Island quarry (92F/9E). Looking northeast. Upper bench is approximately 50 metres above sea level.

Plate 4-8-15. Hardy Island, lower quarry (92F/9E).

Plate 4-8-16. Kelly Island quarry (92F/9E).

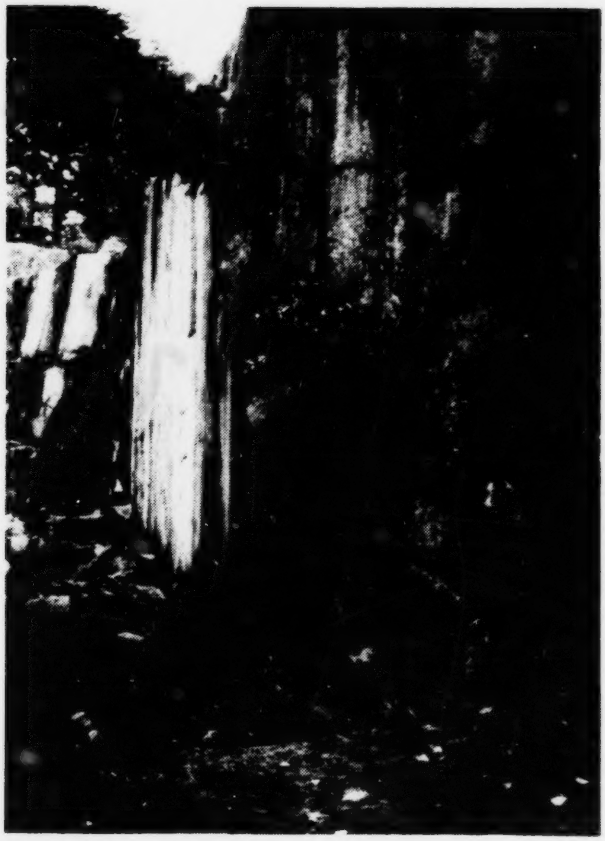

Plate 4-8-17. Kelly Island (92F/9E). Twelve-metre face — Quarry 2.

Plate 4-8-18. Fox Island quarry (92F/9E). Looking north.

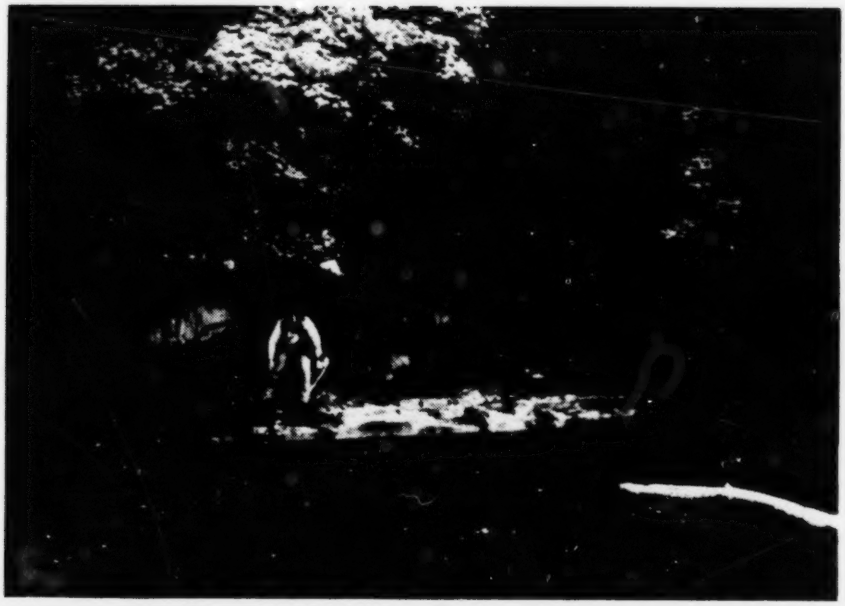

Plate 4-8-19. Nootka Sound quarry (92F/15E).

Coal Studies

WEARY RIDGE AND BLEASDELL CREEK AREAS
ELK VALLEY COALFIELD*
(82J/7)

By D. A. Grieve

INTRODUCTION

Detailed geological mapping and sampling of the north half of the Elk Valley Coalfield (Figure 5-1-1) began this year as part of the ongoing evaluation of the East Kootenay coal district by the Geological Survey Branch. The end result, a 10 000-scale geological map on an orthophoto base, will extend previous mapping coverage a distance of 40 kilometres to the north, from the general vicinity of Britt and Henretta Creeks to the Elk Lakes Provincial Park (Figure 5-1-2). Work in 1986 was restricted to the area between Britt and Henretta Creeks to the south, and Weary Creek to the north (Figure 5-1-2). This article describes geology and coal rank distribution for the Weary Ridge and Bleasdell Creek areas.

The Weary Ridge-Bleasdell Creek area lies in the Elk River valley, 35 to 40 kilometres north of Elkford and 15 to 20 kilometres north of Fording Coal Ltd.'s Fording River operations. It is accessible by two-wheel-drive vehicle from Elkford, although access to some localities requires four-wheel drive.

Relief in the area is not extreme. Weary Ridge rises to a maximum elevation of 2200 metres, 650 metres above the floor of the Elk Valley. Topography near lower Bleasdell Creek rises gradually above the Elk River, but steepens dramatically towards Mount Bleasdell, outside the study area.

The area is licenced Crown land and comprises part of two separate properties. The south end of Weary Ridge is part of the Fording River property, owned by Fording Coal; the remainder of the area is part of the Elk River property, owned 50 per cent by Fording Coal, with ownership of the other 50 per cent shared by Stelco Inc., Scurry-Rainbow Oil Ltd. and Home Oil Co. Ltd. Fording acquired its interest in the property in 1986.

Recent coal exploration on Weary Ridge began in 1968, when North American Coal Corp. conducted an extensive program of trenching, drilling and underground work. In 1969 Scurry-Rainbow completed a similar program covering both Weary and Little Weary Ridges. Subsequent programs were concentrated on Little Weary Ridge, but included work on the northern part of Weary Ridge. Operators were Emkay Canada Natural Resources Ltd. and Scurry-Rainbow Oil Ltd. between 1970 and 1972, Elco Mining Ltd. and Exploration und Bergbau GmbH in 1975 and 1976, and Elco Mining Ltd. in 1976 and 1977. A surface mine plan for Little Weary Ridge was given government approval-in-principle in 1979.

Exploration in the Bleasdell Creek area was mainly confined to 1969, when Scurry-Rainbow Oil carried out trenching, drilling and adit construction.

FIELDWORK AND METHODS OF STUDY

Field data were plotted directly on British Columbia Government air photographs, enlarged to approximately 1:7500 scale. Data were later transferred to 1:10 000-scale orthophotos, prepared especially for this project.

A stratigraphic section of Mist Mountain Formation on Weary Ridge was measured using a 1.5-metre "pogo stick".

Grab samples of coal were taken to provide material for petrographic rank determinations. In all cases, bloom and other highly degraded coal was avoided, usually by sampling from fresh-looking cuts or by digging through softer material.

Three 1969 diamond-drill cores from Weary Ridge were logged in detail using the method of Ruby *et al.* (1981) as described by Grieve and Elkins (1986). Although most of the coal had been removed for analysis, it was possible to sample thin seams and coal bands for petrographic rank determinations. Results of core logging and sampling are not yet available.

Petrographic rank of coal was determined by the $\bar{R}_o$ max method (mean maximum vitrinite reflectance in oil). Maximum readings on 50 grains per sample were measured and averaged. Coals are classified into ASTM rank categories as follows: high volatile bituminous, $\bar{R}_o$ max <1.12 per cent; medium volatile bituminous, 1.12 per cent $<\bar{R}_o$ max <1.51 per cent; and low volatile bituminous, $\bar{R}_o$ max >1.51 per cent.

STRATIGRAPHY

The stratigraphic column in the study area is shown as the legend in Figure 5-1-3. Economic coals in southeastern British Columbia are contained within the Mist Mountain Formation of the Jurassic-Cretaceous Kootenay Group. A thin coal seam is known to occur within the underlying Morrissey Formation (basal Kootenay sandstone) but was not observed. In addition, thin humic and sapropelic coals occur throughout the Elk Formation. The Kootenay Group is overlain by Cadomin Formation, the basal conglomerate unit of the Lower Cretaceous Blairmore Group.

A stratigraphic section of 507 metres of the Mist Mountain Formation, measured along Weary Ridge, is shown in Figure 5-1-4. Coal seams are exposed in trenches excavated for bulk sampling in 1968. An estimated additional 50 metres of Mist Mountain Formation, containing two or three thin coal seams, is present on Weary Ridge. This is overlain in turn by a resistant sandstone unit, believed to be the basal unit of the Elk Formation, which forms a prominent dip slope at the south end of the ridge.

The coal seam nomenclature used in Figure 5-1-4 corresponds with that applied by North American Coal. A total of 63.8 metres of coal occurs in approximately 15 seams or zones, ranging from 1.6 metres (G-seam) to 9 metres in thickness (S-seam). The most economically attractive part of the section appears to be the uppermost 150 metres, which contains 29 metres of coal in four zones (N, P, Q and S). The uppermost of these, S-seam, correlates with the burning seam south of Aldridge Creek (Bustin and Mathews, 1982).

An intriguing aspect of the Weary Ridge section is the relative scarcity of discrete, thick sandstone units (Figure 5-1-4). A prominent sandstone overlies S-seam, and three thin sandstone units occur within the section, but for the most part, sandstone is fine or very fine grained and occurs as interbedded sandstone-siltstone sequences. This suggests that fluvial channels were remote during most of the deposition of the Mist Mountain Formation and may account for the good development of coal at this location.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

South of Bleasdell Creek the basal part of the Mist Mountain Formation has been faulted out, while north of the creek the entire formation is preserved. The stratigraphy of the formation on the west side of the Elk Valley appears generally similar to that on Weary Ridge.

STRUCTURE

The Weary Ridge-Bleasdell Creek area is underlain by both limbs of the north-trending Alexander Creek syncline (Figure 5-1-3), which extends throughout the Elk Valley Coalfield. The west limb ranges from steeply east-dipping to overturned and steeply west-dipping. It is over-ridden by the west-dipping Bourgeau thrust fault, which has placed Triassic and older rocks in contact with either Fernie or Kootenay strata (Figure 5-1-3). The flatter east limb dips 40 to 45 degrees to the west.

Local structural disturbances are mainly associated with the Bourgeau thrust. At Coal Creek, a tributary of Bleasdell Creek, the lower Mist Mountain Formation is cut by imbricate thrusts; local thickening of a coal seam is present in this highly disturbed zone.

RANK DISTRIBUTION

Sample analysis for rank determination is on-going. Reflectance values obtained to date on samples from the Weary Ridge measured section are displayed in Figure 5-1-4. Values for some samples from Weary Creek, Coal Creek, and a series of trenches less than 1 kilometre north of Bleasdell Creek have also been determined.

Based on results obtained so far, there is a striking and significant contrast in coal rank between the east and west limbs of the Alexander Creek syncline, with the east limb having the higher rank values. For example, on Weary Ridge reflectance values range from 1.59 to 1.15 per cent (Figure 5-1-4) corresponding with low and medium volatile bituminous coals. Values obtained on samples in Weary Creek, representing approximately the same interval as seams B to I or J, range from 1.63 to 1.43 per cent.

In marked contrast, values obtained on samples collected north of Bleasdell Creek, representing the interval from the basal to the uppermost coal-bearing zone of the Mist Mountain Formation, range from 0.85 to 0.65 per cent. Values from Coal Creek, less than 1 kilometre south of Bleasdell Creek, range from 0.86 to 0.89 per cent, with the exception of one value of 1.00 per cent.

These results corroborate work by Hughes and Cameron (1986) in the same general area. Hughes and Cameron have also found similar abrupt rank changes across other large overturned folds in the footwalls of major thrust faults. However, no other similar situations are so far known in southeastern British Columbia. Based on modelling of the coalification in this and similar cases, Hughes and Cameron speculate that the deformation of Kootenay strata directly affected deposition of Upper Cretaceous sediments, leading to significant and abrupt contrasts in depth of burial.

MINEABILITY

Preliminary evaluation suggests that Weary Ridge offers significant potential as a surface minesite. At the south end of the ridge the N to S-seam interval is near the surface and offers the combination of the lowest coal ranks on Weary Ridge with the most attractive apparent waste-to-coal ratio (Figure 5-1-4). The presence of basal Elk Formation covering the south end of the ridge is a negative feature, but the volume of material is probably not great (Figure 5-1-3).

ACKNOWLEDGMENTS

Kevin Switzer provided excellent field assistance. Joanne Schwemler carried out all petrographic analyses. Fording Coal gave permission to log and sample drill core.

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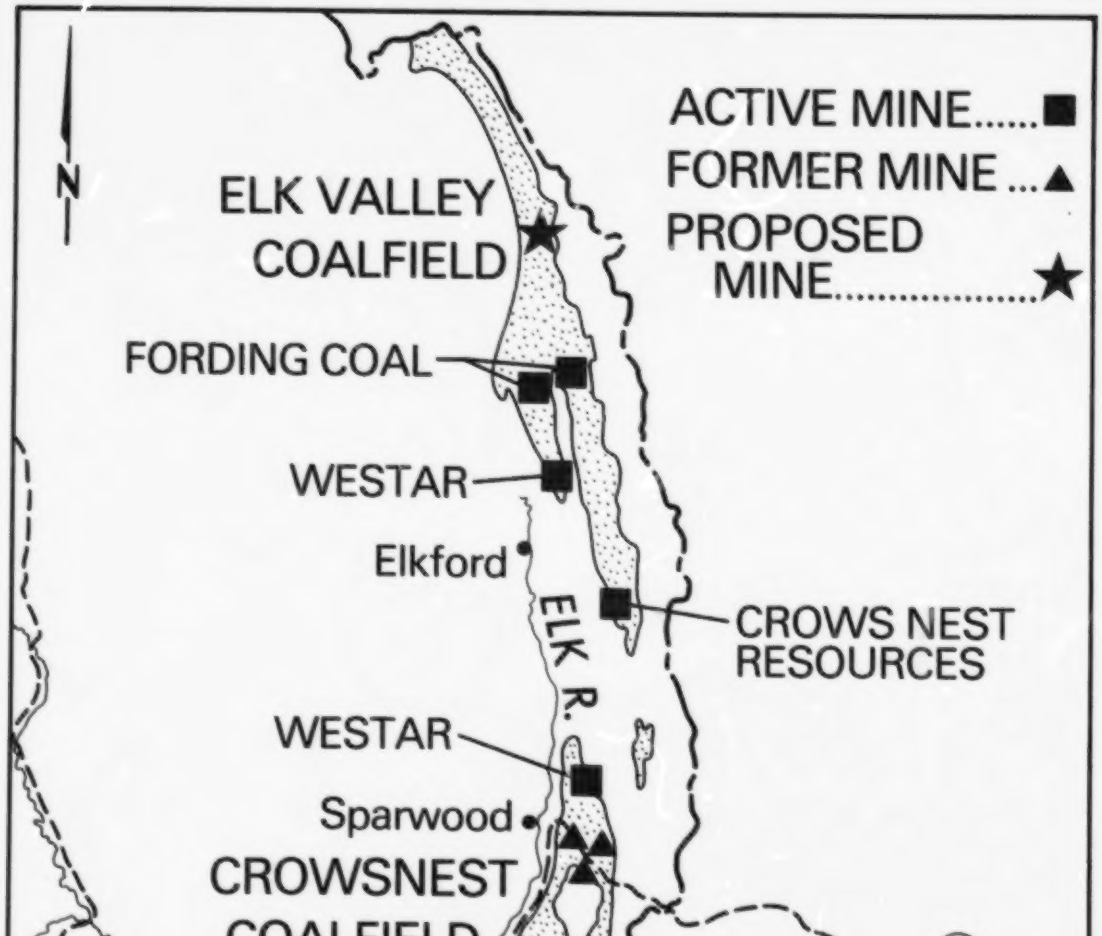
N
ACTIVE MINE...... ■
FORMER MINE ... ▲
PROPOSED MINE........ ★
ELK VALLEY COALFIELD
FORDING COAL
WESTAR
Elkford
ELK R.
CROWS NEST RESOURCES
WESTAR
Sparwood
CROWSNEST COALFIELD
Cranbrook
Fernie
BYRON CREEK COLLIERIES
3
3 93
3
93
FLATHEAD COALFIELD
ALBERTA
B.C.
0
30
Kilometres
U.S.A.

Figure 5-1-1. East Kootenay coalfields with mine properties located.

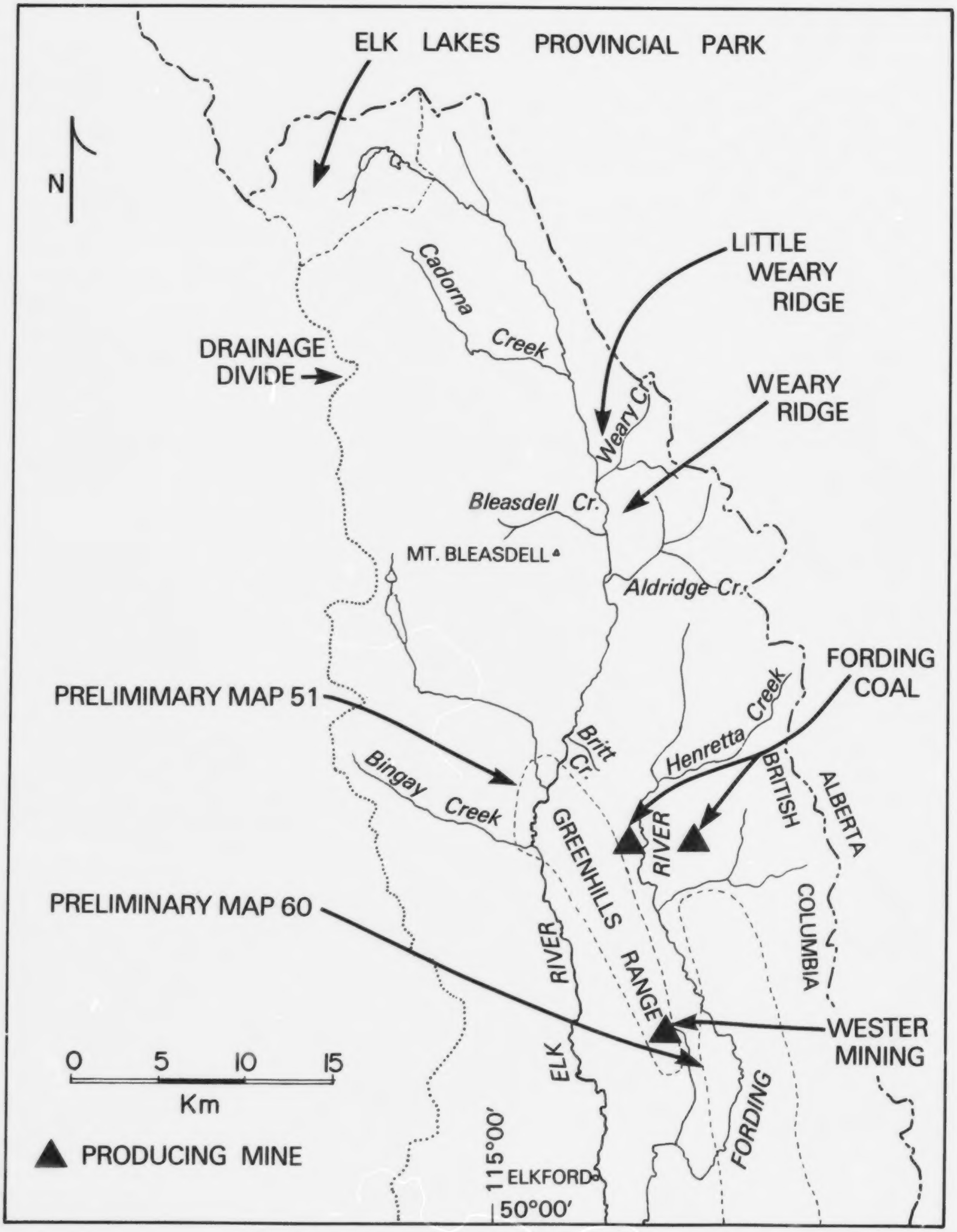
ELK LAKES PROVINCIAL PARK
N
LITTLE WEARY RIDGE
Cadorna Creek
DRAINAGE DIVIDE
Weary Cr.
WEARY RIDGE
Bleasdell Cr.
MT. BLEASDELL
Aldridge Cr.
FORDING COAL
PRELIMIMARY MAP 51
Henretta Creek
Britt Cr.
Bingay Creek
GREENHILLS RANGE
RIVER
BRITISH COLUMBIA
ALBERTA
PRELIMINARY MAP 60
ELK RIVER
WESTER MINING
FORDING
0 5 10 15
Km
PRODUCING MINE
115°00'
ELKFORD
50°00'

Figure 5-1-2. Location map of the Elk River valley north of Elkford.

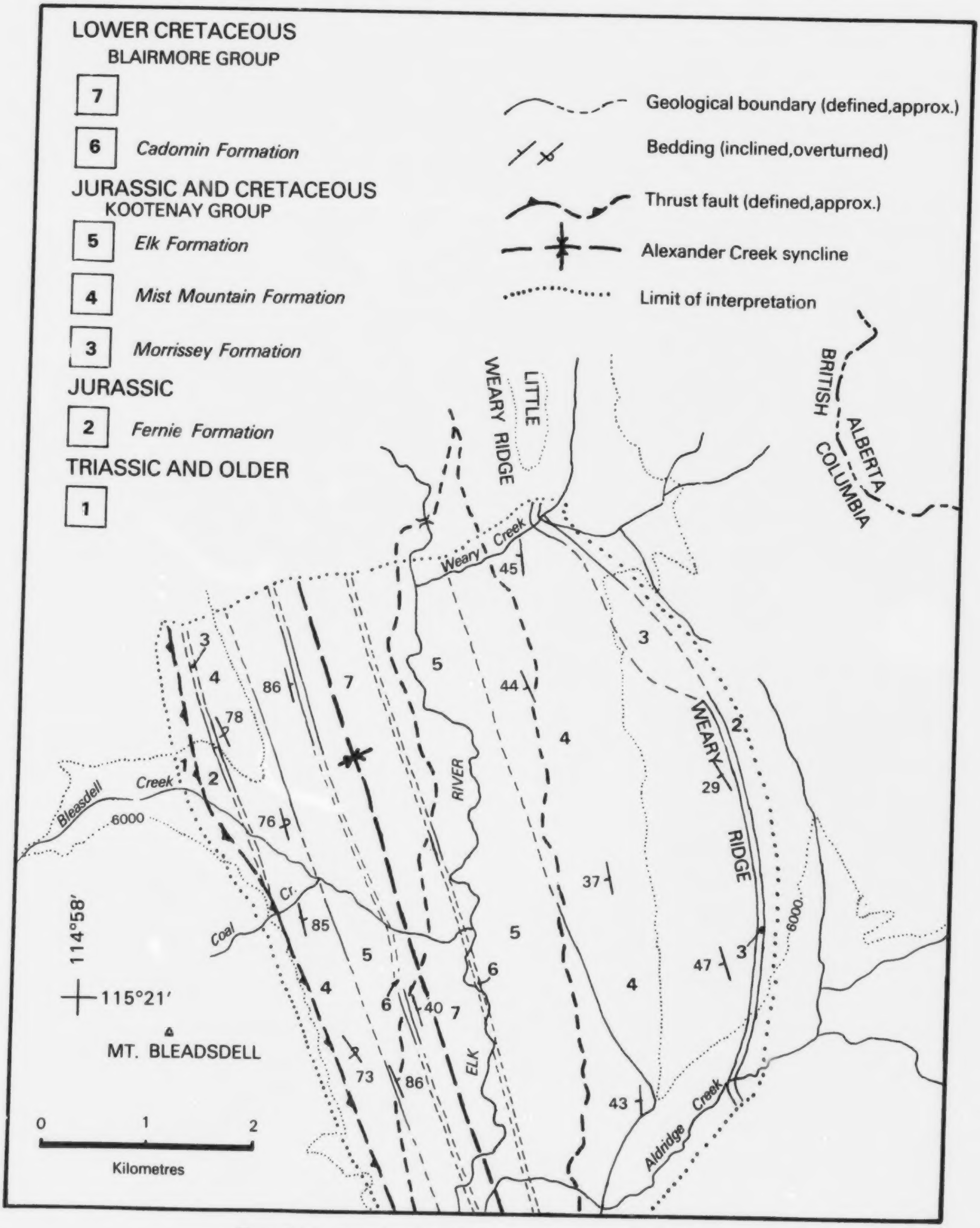
LOWER CRETACEOUS
BLAIRMORE GROUP
7
6 Cadomin Formation
JURASSIC AND CRETACEOUS
KOOTENAY GROUP
5 Elk Formation
4 Mist Mountain Formation
3 Morrissey Formation
JURASSIC
2 Fernie Formation
TRIASSIC AND OLDER
1
Geological boundary (defined,approx.)
Bedding (inclined,overturned)
Thrust fault (defined,approx.)
Alexander Creek syncline
Limit of interpretation
LITTLE WEARY RIDGE
BRITISH COLUMBIA
ALBERTA
Weary Creek
WEARY RIDGE
RIVER
ELK
Bleasdell Creek
Coal Cr.
Aldridge Creek
6000
114°58′
115°21′
MT. BLEADSDELL
0
1
2
Kilometres
45
44
86
78
76
85
37
29
47
40
73
86
43

Figure 5-1-3. General geology of the Weary Ridge-Bleasdell Creek area.

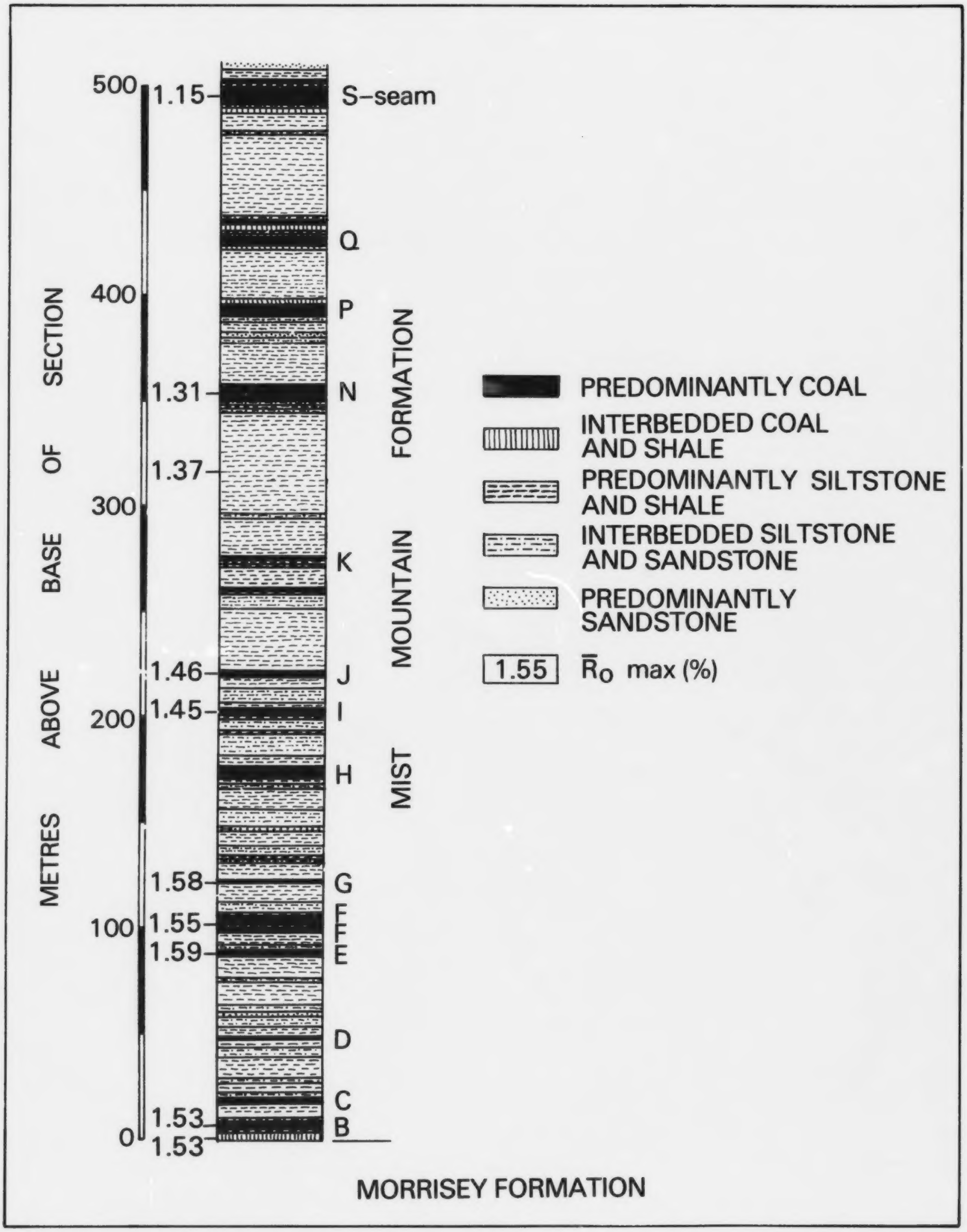
METRES ABOVE BASE OF SECTION
500
400
300
200
100
0
1.15
1.31
1.37
1.46
1.45
1.58
1.55
1.59
1.53
1.53
S–seam
Q
P
N
K
J
I
H
G
F
F
E
D
C
B
MIST MOUNTAIN FORMATION
MORRISEY FORMATION
PREDOMINANTLY COAL
INTERBEDDED COAL AND SHALE
PREDOMINANTLY SILTSTONE AND SHALE
INTERBEDDED SILTSTONE AND SANDSTONE
PREDOMINANTLY SANDSTONE
1.55 R̄o max (%)

Figure 5-1-4. Generalized measured section of the Mist Mountain Formation on Weary Ridge.

SUBSURFACE COAL RANK PROFILES
EWIN PASS TO BARE MOUNTAIN
ELK VALLEY COALFIELD
SOUTHEASTERN BRITISH COLUMBIA
(82G/15, 82J/2)

By D. A. Grieve

INTRODUCTION

During detailed lithological logging of selected drill cores from the south half of the Elk Valley Coalfield in 1985 (Grieve and Elkins, 1986) approximately 80 coal samples were collected for petrographic rank ($\bar{R}_o$ max) determinations. The goal was to calculate down-hole rank gradients, in order to discover if variations in gradients correspond with observed regional rank variations.

There was no intent to attempt correlation of coal seams with petrographic data, as regional rank variations make this impossible. Analysis of lithological data collected during this project is continuing, however, with the purpose of effecting further correlations.

METHODS OF STUDY

Small grab samples of coal were collected from very thin seams and coal bands, as almost all coal had been removed from core boxes for analysis by the coal companies. The depth of each sample was recorded.

Petrographic rank was determined by the $\bar{R}_o$ max method (mean maximum reflectance in oil). Fifty grains per sample were read and the results averaged. Coals are classified into ASTM rank categories as follows: high volatile bituminous, $\bar{R}_o$ max <1.12 per cent; medium volatile bituminous, 1.12 per cent $<\bar{R}_o$ max <1.51 per cent.

STRATIGRAPHIC SETTING

All coal samples collected were from the Mist Mountain Formation of the Jurassic-Cretaceous Kootenay Group. In the study area the formation has an average thickness of 500 to 600 metres, and consists of a nonmarine, interbedded sequence of siltstone, sandstone, mudstone, shale, coal and conglomerate. To date two coal-bearing horizons have been correlated throughout the study area (Grieve and Elkins, 1986). The basal coal zone, which occupies the basal 20 metres of the Mist Mountain Formation, consistently includes a thin coal seam directly in contact with the underlying Morrissey Formation. The Imperial coal seam occupies a position roughly 150 metres stratigraphically above the base of the Mist Mountain Formation.

RESULTS

Drill hole locations are shown in Figure 5-2-1, while $\bar{R}_o$ max versus depth plots for the drill holes are shown in Figures 5-2-2 to 5-2-8.

EP-102: $\bar{R}_o$ max values from Ewin Pass drill hole EP-102 range from 1.12 to 1.30 per cent (Figure 5-2-2). The highest value (sample 9) represents a horizon roughly 40 metres stratigraphically above the base of the Mist Mountain Formation. Sample 6, from the floor of the Imperial seam, has a value of 1.19 per cent, while sample 5, from the roof, has a value of 1.24 per cent.

EP-105: $\bar{R}_o$ max values from Ewin Pass drill hole EP-105 range from 0.95 to 1.26 per cent (Figure 5-2-3). Sample 14, with the highest value, represents a nearly identical horizon to sample 2 from EP-102, which has a value of 1.18 per cent. Likewise, a value of 1.18 per cent in EP-105 (sample 15) can be compared with 1.12 per cent, the lowest value in EP-102 (sample 1). The lowest value in EP-105 (sample 10) represents a horizon within approximately 40 metres of the top of the Mist Mountain Formation.

MBE-101: $\bar{R}_o$ max values from Mount Banner drill hole MBE-101 range from 1.34 to 1.42 per cent (Figure 5-2-4). The highest value, from sample 81, represents a horizon roughly 80 metres above the base of the Mist Mountain Formation. Sample 79, with a value of 1.39 per cent, is believed to represent a nearly identical horizon to samples 14 (1.26 per cent) and 2 (1.18 per cent) from holes EP-105 and 102, respectively.

EV-150 and 151: Values from closely spaced Ewin Creek drill holes EV-150 and 151 range from 1.11 to 1.46 per cent (Figures 5-2-5 and 5-2-6). Samples 28 and 29 from EV-151 (values of 1.46 and 1.40 per cent respectively) and sample 37 from EV-150 (1.43 per cent) are from the basal coal zone. A thrust fault in EV-150 (Figure 5-2-5) has produced an apparent thickness duplication of 80 metres between the basal coal zone and the Imperial seam. Corresponding samples from near the floor of the Imperial seam have values of 1.24 per cent and 1.38 per cent (sample 30 from EV-150 and sample 24 from EV-151, respectively). The latter value contrasts with that from sample 23 (1.20 per cent) from the roof of the Imperial seam in the same hole.

BM81-1 and 2: Values from the closely spaced Bare Mountain drill holes, BM81-1 and 2, range from 1.05 to 1.50 per cent (Figures 5-2-7 and 5-2-8). A thrust fault in BM81-2 (Figure 5-2-8) has produced an apparent thickness duplication of 127 metres, including duplication of the basal portion of the Mist Mountain Formation. Corresponding values from the basal coal zone intersected in BM81-2 are 1.50 per cent (sample 59, lower plate) and 1.42 per cent (sample 54, upper plate). The corresponding value from BM81-1 is 1.47 per cent (sample 77). Sample 46, from the floor of the Imperial seam in BM81-2, has a value of 1.38 per cent. Samples 60 to 65 from BM81-1, with a range of 1.05 to 1.15 per cent, represent the uppermost portion of the Mist Mountain Formation.

DISCUSSION

Results indicate that coals in this portion of the Elk Valley Coalfield are predominantly medium volatile bituminous in rank, with some high volatile coals in the upper portion of the Mist Mountain Formation, most notably at Ewin Pass. Based on the limited comparisons possible, rank values for a given stratigraphic horizon are lowest at Ewin pass, a result which is corroborated by field sampling (Grieve and Fraser, 1985). All other areas represented by these drill holes have similar rank values, a result not corroborated by field sampling, which suggests that Mount Banner

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British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

samples are anomalously high. Nonetheless, the trend of decreasing volatiles from south to north in samples 2, 14 and 79 from the same stratigraphic horizon in holes EP-102, EP-105 and MBE-101 (1.18, 1.26 and 1.39 per cent) is quite striking.

The two drill holes with significant fault repetition allow preliminary consideration of the timing of coalification with respect to thrust faulting. In the case of BM81-2, the fact that the samples from the lower plate have higher reflectance values than corresponding samples from the upper plate, and that there is no obvious major offset of the profile by the fault, suggests that a significant amount of post-faulting coalification occurred. In the case of EV-150, it appears there may be a slight offset of the profile by the fault, although the data are sparse. A valid comparison can be made between sample 32 below the fault and samples 30 and 31 above it; the upper plate samples have higher reflectances. Comparison of the Imperial seam values between EV-150 and EV-151 is not valid as the thrust fault in EV-150 has a component of dip in the direction of EV-151.

Any further comparison between drill holes, and calculation of down-hole reflectance gradients, has been frustrated by the amount of data scatter in all the profiles. This scatter was not expected, and its causes are not yet known. Contributing factors may be:

- analytical variability;
- sample variability (whether a sample is from a discrete coal seamlet or a coal band within another rock type);
- variability of the heat flow characteristics of different rock types;
- natural, small-scale variations in reflectance overshadowing the average down-hole variation;
- variability of the bireflectance indicatrix.

With regard to the last factor, almost all samples analysed are biaxial, meaning that $\bar{R}_o$ max is not a unique value of an individual vitrinite grain (Kilby, 1986).

Further work will be applied to the interpretation of the petrographic data presented here, including an attempt to determine to what extent the above factors influence reflectance profiles, and to calculate meaningful average gradients.

ACKNOWLEDGMENTS

JoAnne Schwemler carried out all petrographic analyses. Westar Mining Ltd. and Crows Nest Resources Ltd. gave permission to sample core.

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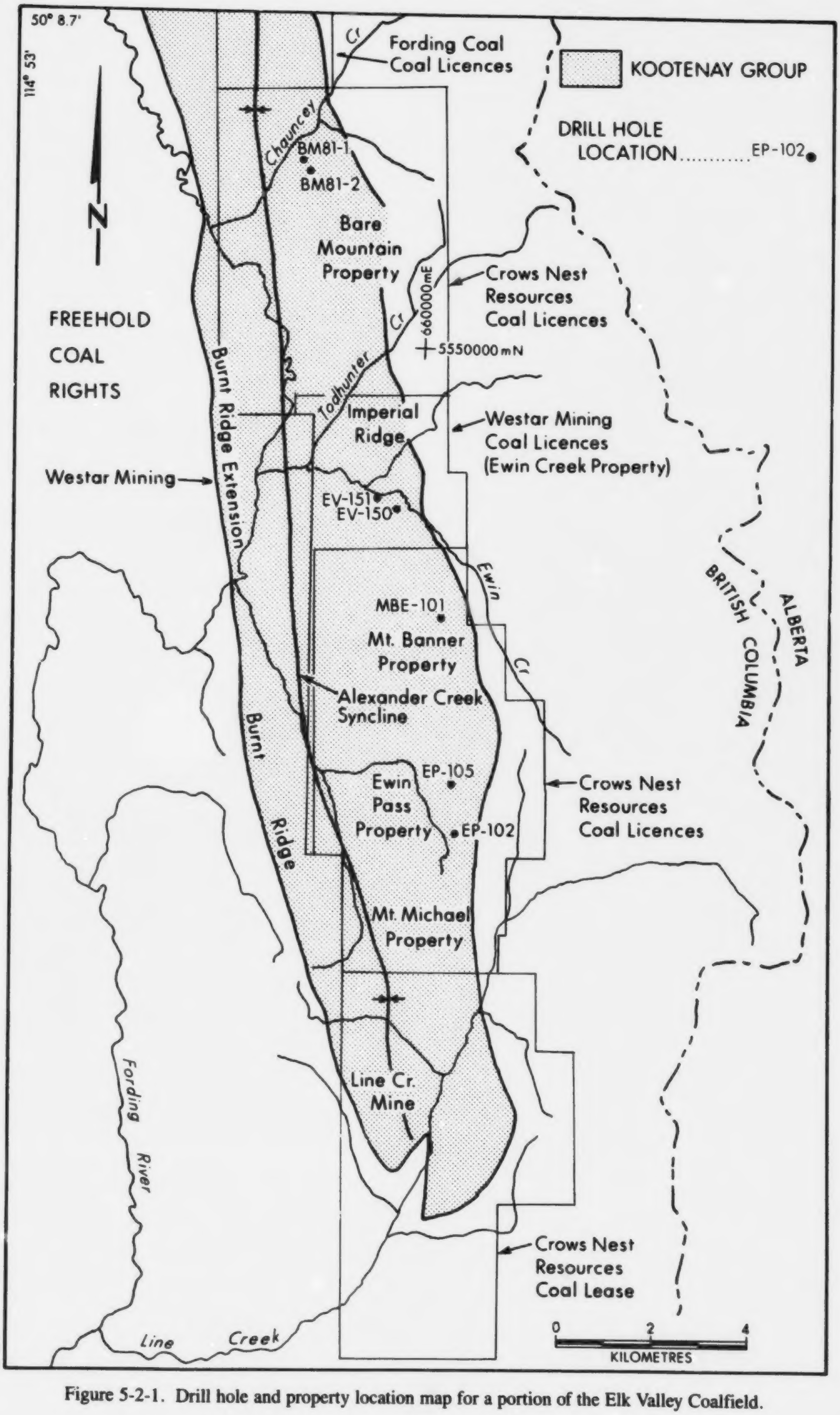
50° 8.7'
114° 53'
N
Fording Coal
Coal Licences
KOOTENAY GROUP
DRILL HOLE
LOCATION............EP-102
Chauncey
BM81-1
BM81-2
Bare
Mountain
Property
Crows Nest
Resources
Coal Licences
660000mE
5550000mN
FREEHOLD
COAL
RIGHTS
Burnt Ridge Extension
Todhunter
Cr
Imperial
Ridge
Westar Mining
Coal Licences
(Ewin Creek Property)
Westar Mining
EV-151
EV-150
Ewin
Cr
MBE-101
Mt. Banner
Property
Alexander Creek
Syncline
BRITISH
COLUMBIA
ALBERTA
Burnt
Ridge
Ewin
Pass
Property
EP-105
EP-102
Crows Nest
Resources
Coal Licences
Mt. Michael
Property
Line Cr.
Mine
Fording
River
Crows Nest
Resources
Coal Lease
Line
Creek
0
2
4
KILOMETRES

Figure 5-2-1. Drill hole and property location map for a portion of the Elk Valley Coalfield.

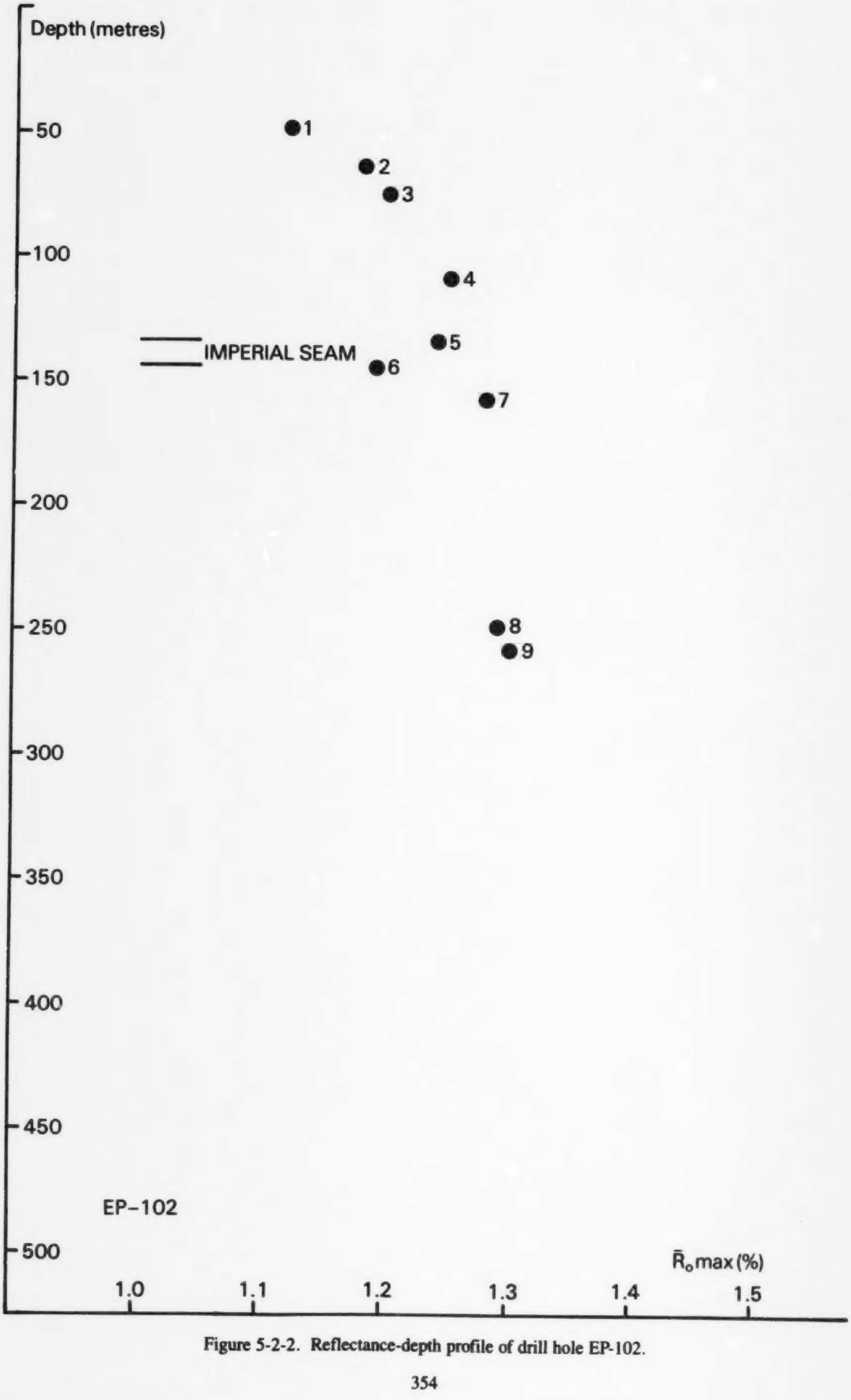

Figure 5-2-2. Reflectance-depth profile of drill hole EP-102.

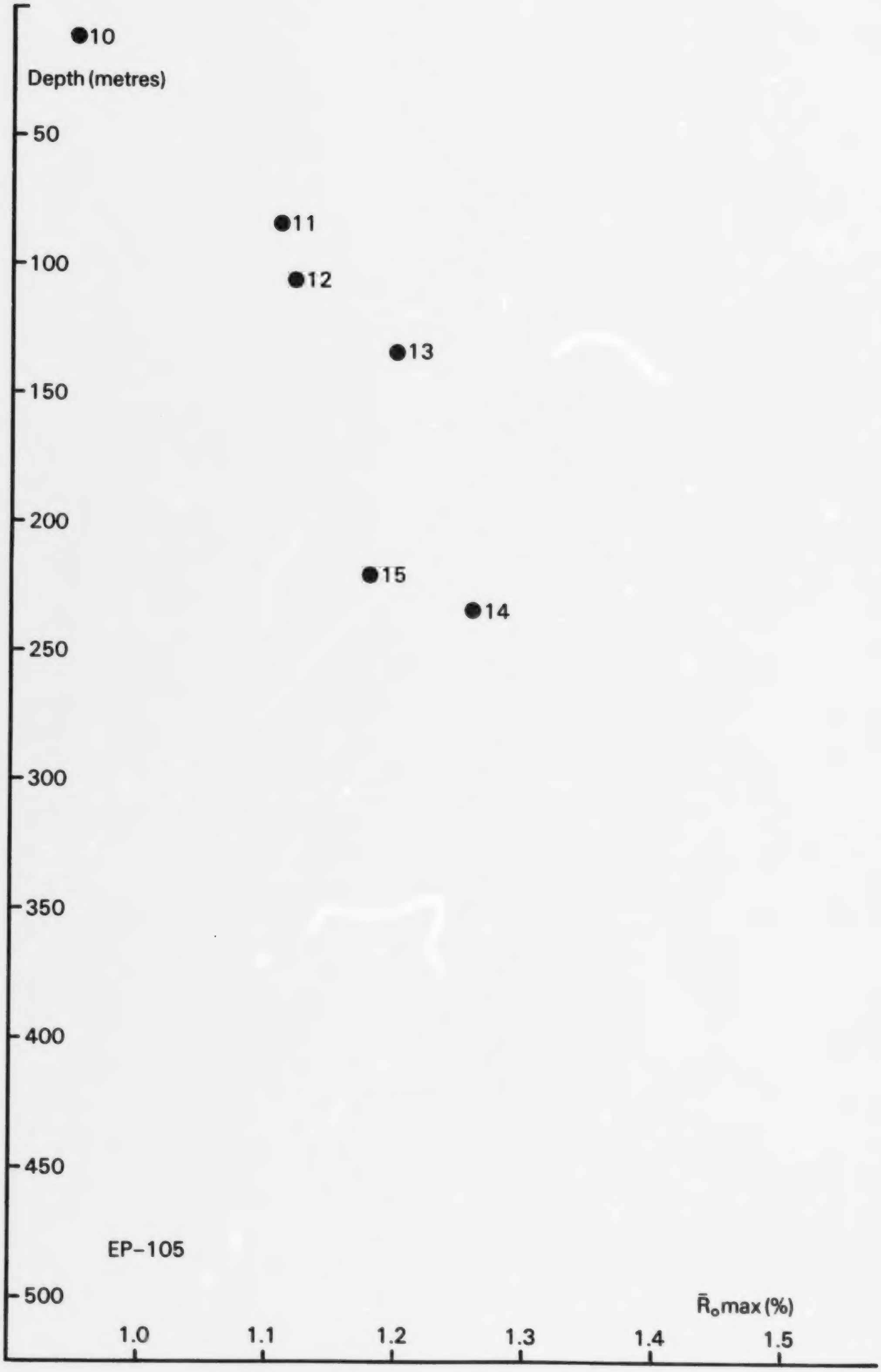

Figure 5-2-3. Reflectance-depth profile of drill hole EP-105.

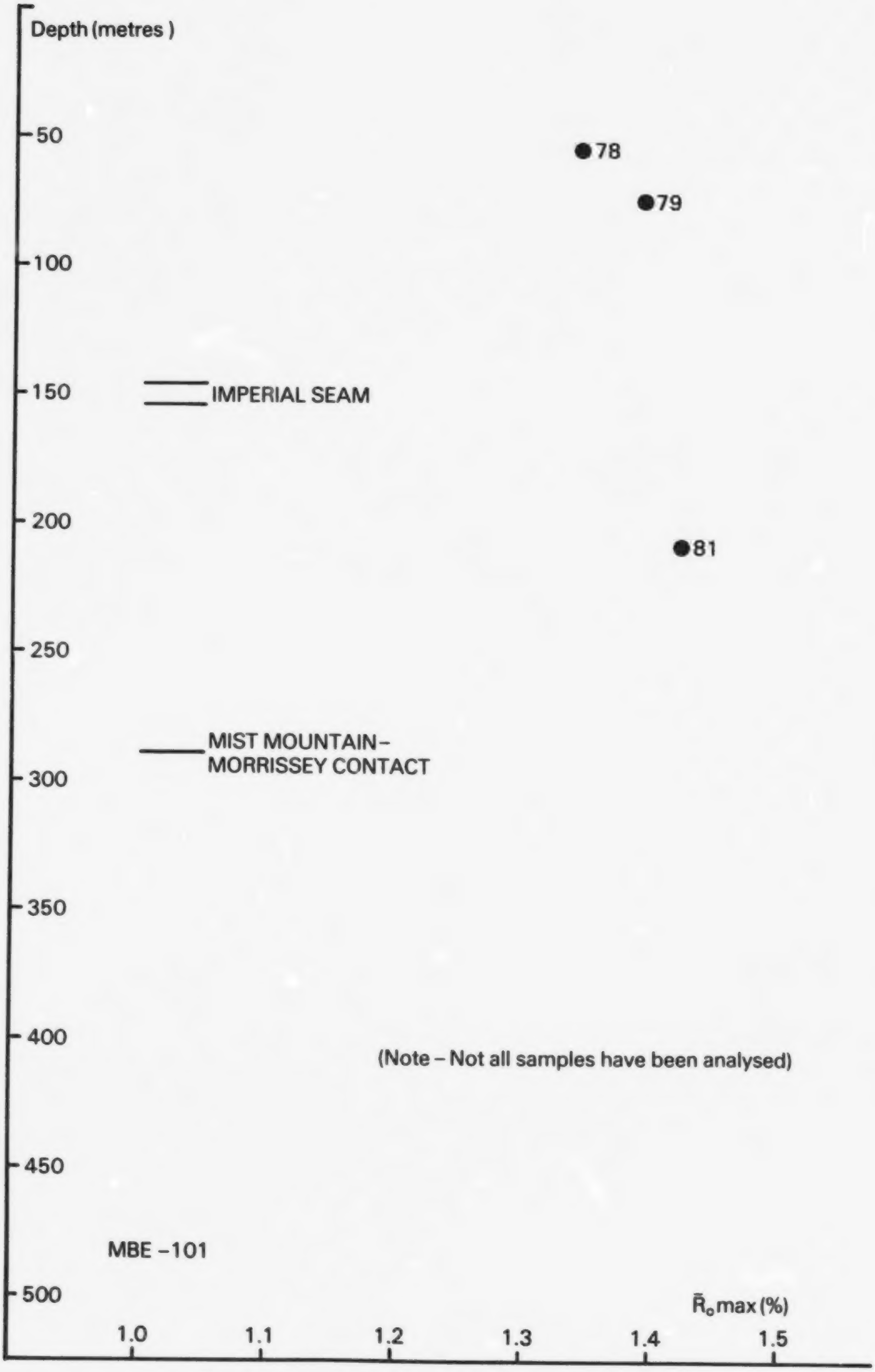

Figure 5-2-4. Reflectance-depth profile of drill hole MBE-101.

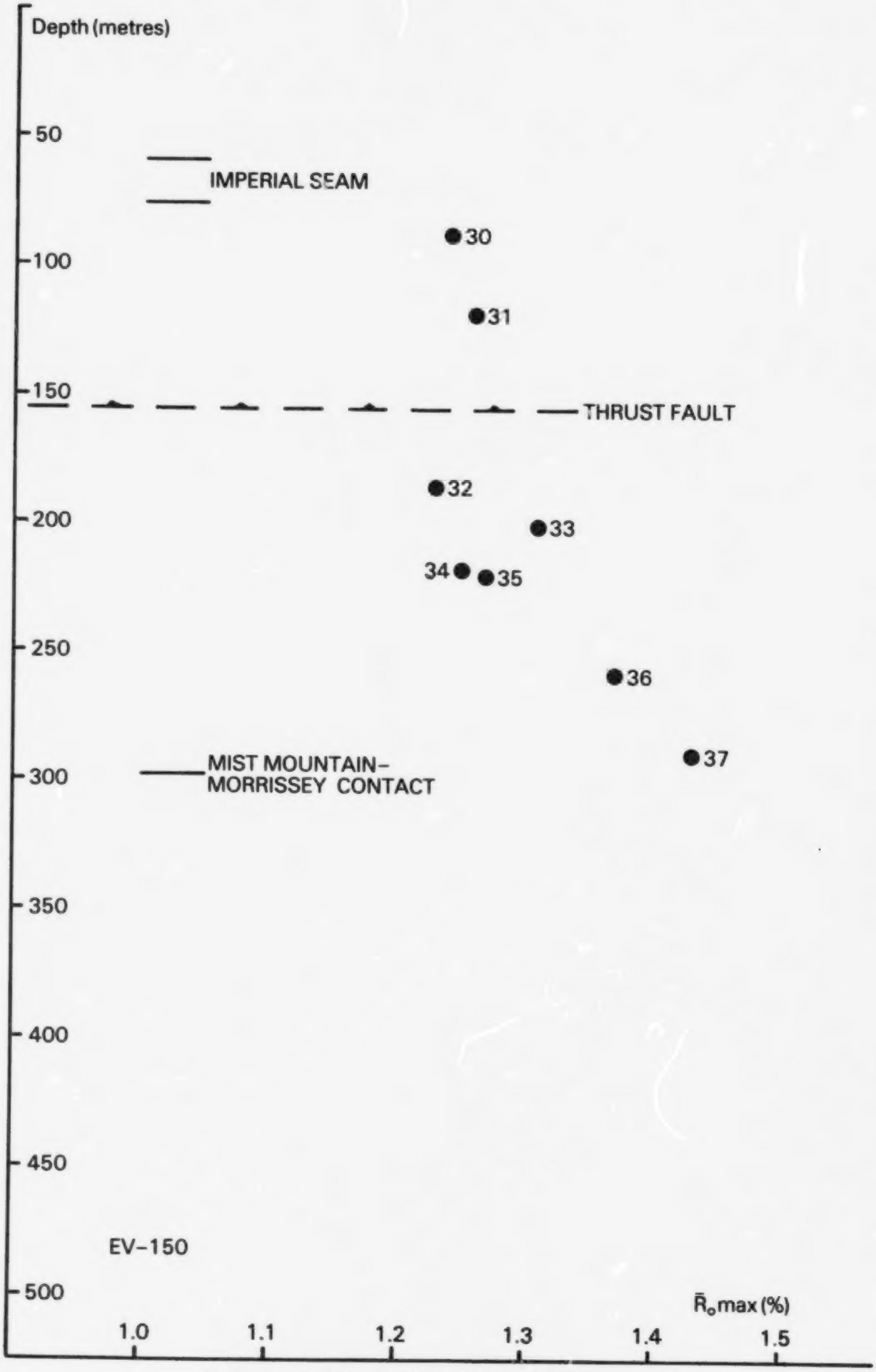

Figure 5-2-5. Reflectance-depth profile of drill hole EV-150.

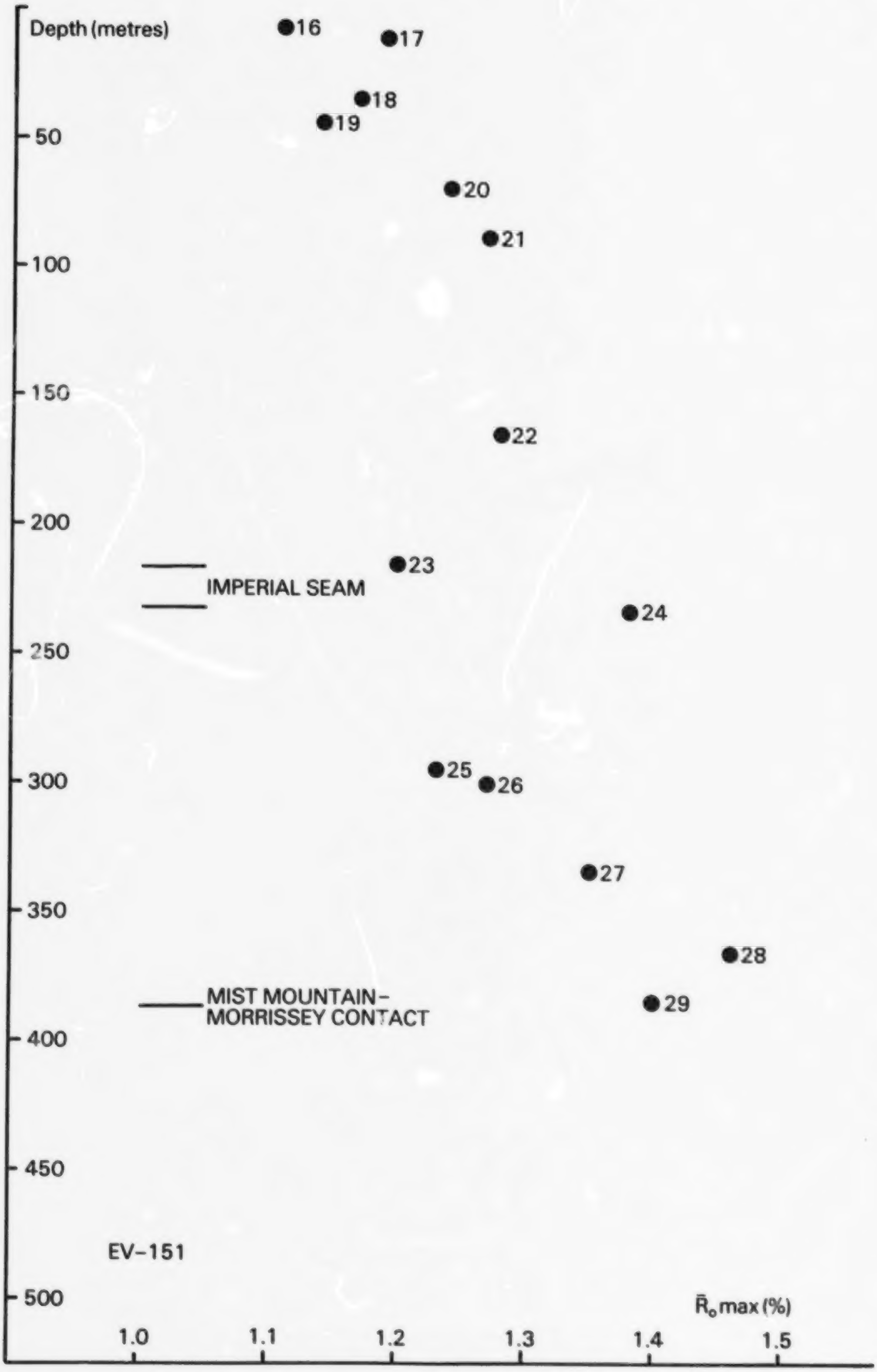

Figure 5-2-6. Reflectance-depth profile of drill hole EV-151.

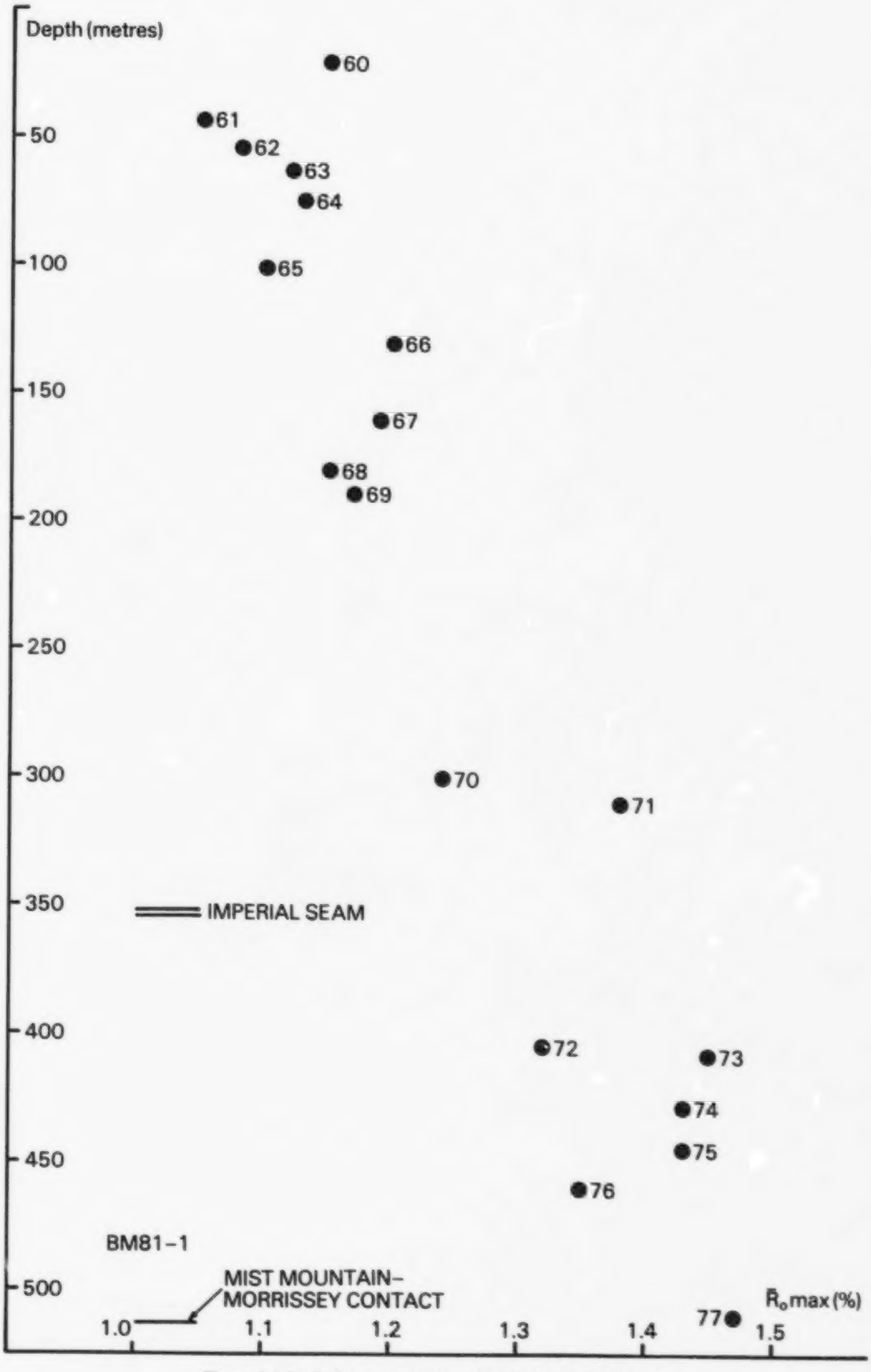

Figure 5-2-7. Reflectance-depth profile of drill hole BM81-1.

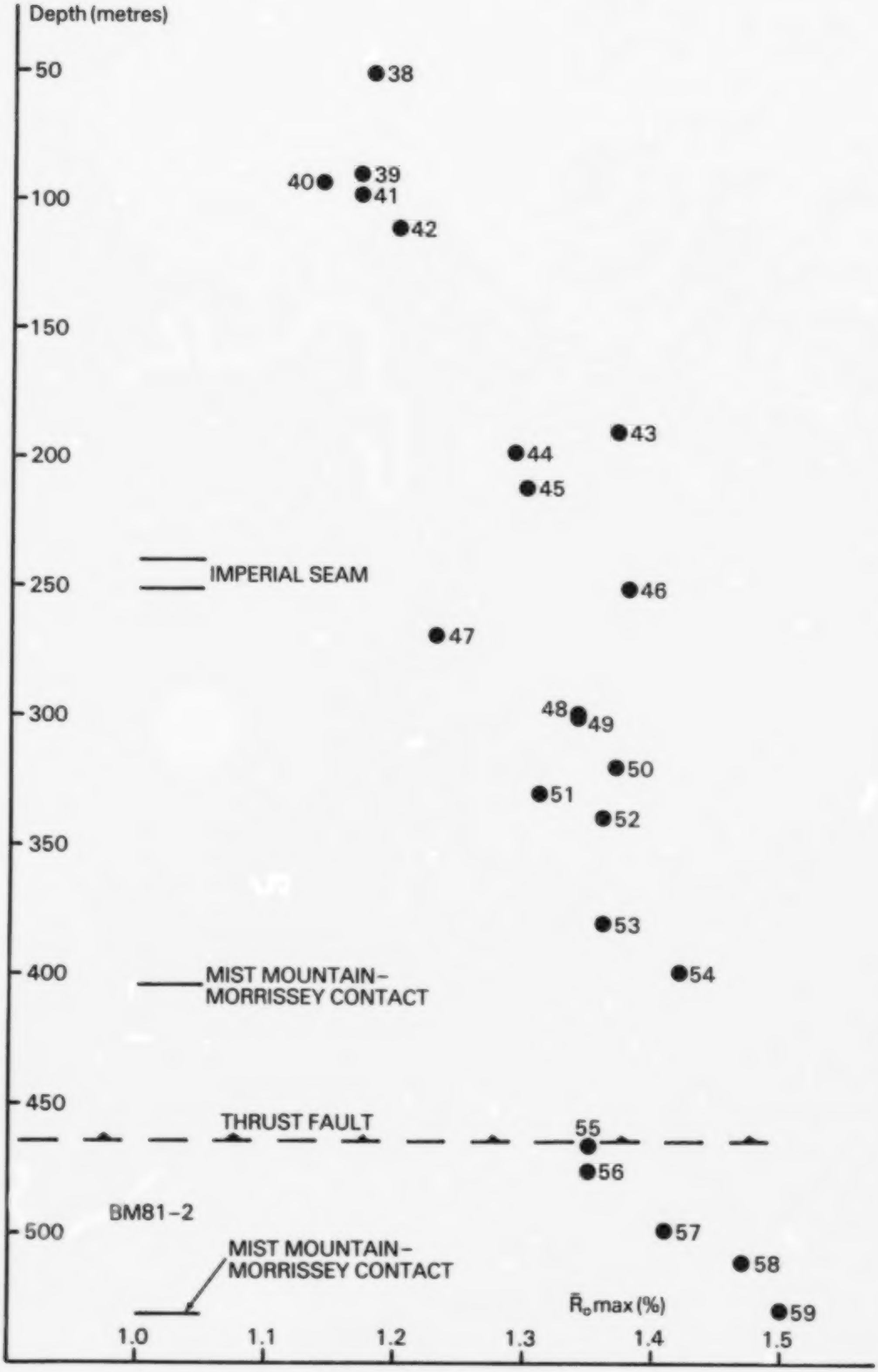

Figure 5-2-8. Reflectance-depth profile of drill hole BM81-2.

COAL RANK DISTRIBUTION
FLATHEAD COALFIELD
SOUTHEASTERN BRITISH COLUMBIA
(82G/2, 82G/7)

By D. A. Grieve

INTRODUCTION

The Flathead Coalfield in southeastern British Columbia consists of four outliers of Kootenay Group rocks in the Flathead River basin, southeast of the Crowsnest Coalfield (Figure 5-3-1; *see also* Figure 5-1-1, this paper). The author carried out reconnaissance geological mapping and coal sampling on the four properties in 1980 (Grieve, 1981). At that time only three of eighteen coal samples were analysed petrographically for rank. This article presents a summary of complete data from the project, supplemented by results from drill core samples collected from two of the four properties, and three deep subsurface coal samples provided by Shell Canada Ltd. from the Shell Middlepass b-94-L/82-G-01 well (Figure 5-3-1).

The Flathead Coalfield is situated in the extreme southeast corner of British Columbia, 35 to 50 kilometres southeast of Fernie. Good access is provided by logging roads from Morrissey, 15 kilometres south of Fernie, via both the Lodgepole-Harvey Creek route and Bighorn-Cabin Creek route to the Flathead River road (Figure 5-3-1). The Lillyburt and Harvey Creek properties, two of the four properties which comprise the coalfield, are adjacent to the Flathead River road. The Cabin Creek road bisects the Sage Creek property and passes south of the Cabin Creek property.

Coal rights to the Lillyburt and Cabin Creek properties are held by Crows Nest Resources Ltd. Sage Creek Coal Ltd. owns the rights at Sage Creek and is awaiting a decision on an application to develop a surface thermal coal mine on the property. Coal rights to the Harvey Creek property are not presently held.

METHODS

Grab samples of coal were collected in the field for petrographic rank determinations. In all cases, bloom and other highly degraded coal was avoided, usually by sampling from fresh-looking cuts or by digging through softer material. In a few cases spoil piles adjacent to adits were sampled and samples of coal were also taken from drill core. As almost all coal seams had been removed from core boxes for analysis, it was necessary to sample very thin seams and coal bands.

Petrographic rank was determined by the $\bar{R}_o$ max method (mean maximum vitrinite reflectance in oil). Maximum readings on 50 grains per sample were measured and then averaged. Coals are classified into ASTM rank categories as follows: high volatile bituminous, $\bar{R}_o$ max <1.12 per cent; medium volatile bituminous, 1.12 per cent $<\bar{R}_o$ max <1.51 per cent.

GEOLOGICAL SETTING

Coal in southeastern British Columbia is contained in the Jurassic-Cretaceous Kootenay Group. In ascending order, the Kootenay Group consists of the Morrissey, Mist Mountain and Elk Formations. The Mist Mountain Formation is the major coal-bearing unit and the Elk Formation contains sporadic thin seams.

The Kootenay Group in Flathead Coalfield is anomalously thin. While this is a result of both the Mist Mountain and Elk Formations being relatively thin, the most notable contrast is between the Mist Mountain Formation in the Flathead Coalfield and in other areas. Its average thickness at the Lillyburt, Harvey Creek and Sage Creek properties is 150 metres, compared with roughly 500 metres in the other two coalfields of southeastern British Columbia. Consequently only three or four major coal seams or zones are present. The Cabin Creek property covers an erosional remnant of 75 metres of Mist Mountain Formation containing two coal seams.

In common with all coal deposits in southeastern British Columbia, the Flathead Coalfield is part of the Lewis (and possibly higher) thrust sheets. The Lillyburt and Harvey Creek properties lie in the immediate hangingwall of the Flathead normal fault (Figure 5-3-1, Price, 1962).

RESULTS

A summary of petrographic rank values of samples from the Flathead Coalfield is presented in Table 5-3-1. A depth-reflectance profile of samples from drill hole LB-301 is shown in Figure 5-3-2.

LILLYBURT

Values of $\bar{R}_o$ max on coal samples from the Lillyburt property range from 1.05 per cent to 1.30 per cent (Table 5-3-1).

The lowest value corresponds with an outcrop sample from relatively high in the section. Coals from the basal portion of the Mist Mountain Formation, sampled only in core from drill hole LB-301, have values of 1.16 and 1.21 per cent. Curiously, higher reflectance values were obtained higher in the Mist Mountain section, both in field and core samples. Elk Formation samples from the core have similar reflectance values to the basal Mist Mountain sample. In fact, the reflectance-depth profile in hole LB-301 is distinctive both in terms of the wide scatter of the data and the apparent lack of dependence of rank on stratigraphic position (Figure 5-3-2).

HARVEY CREEK

The single sample collected from the Harvey Creek property has a reflectance of 1.33 per cent (Table 5-3-1). Its exact stratigraphic position is unknown, but it is believed to be from the lower portion of the Mist Mountain Formation.

SAGE CREEK

Samples collected from the Sage Creek property exhibit a range of reflectance values from 1.03 to 1.20 per cent (Table 5-3-1). The highest value corresponds with the basal seam of the Mist Mountain Formation. A value of 1.12 per cent was obtained on samples from the middle and upper portions of the formation. A single core sample representing a thin coal in the Elk Formation gave a value of 1.03 per cent.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

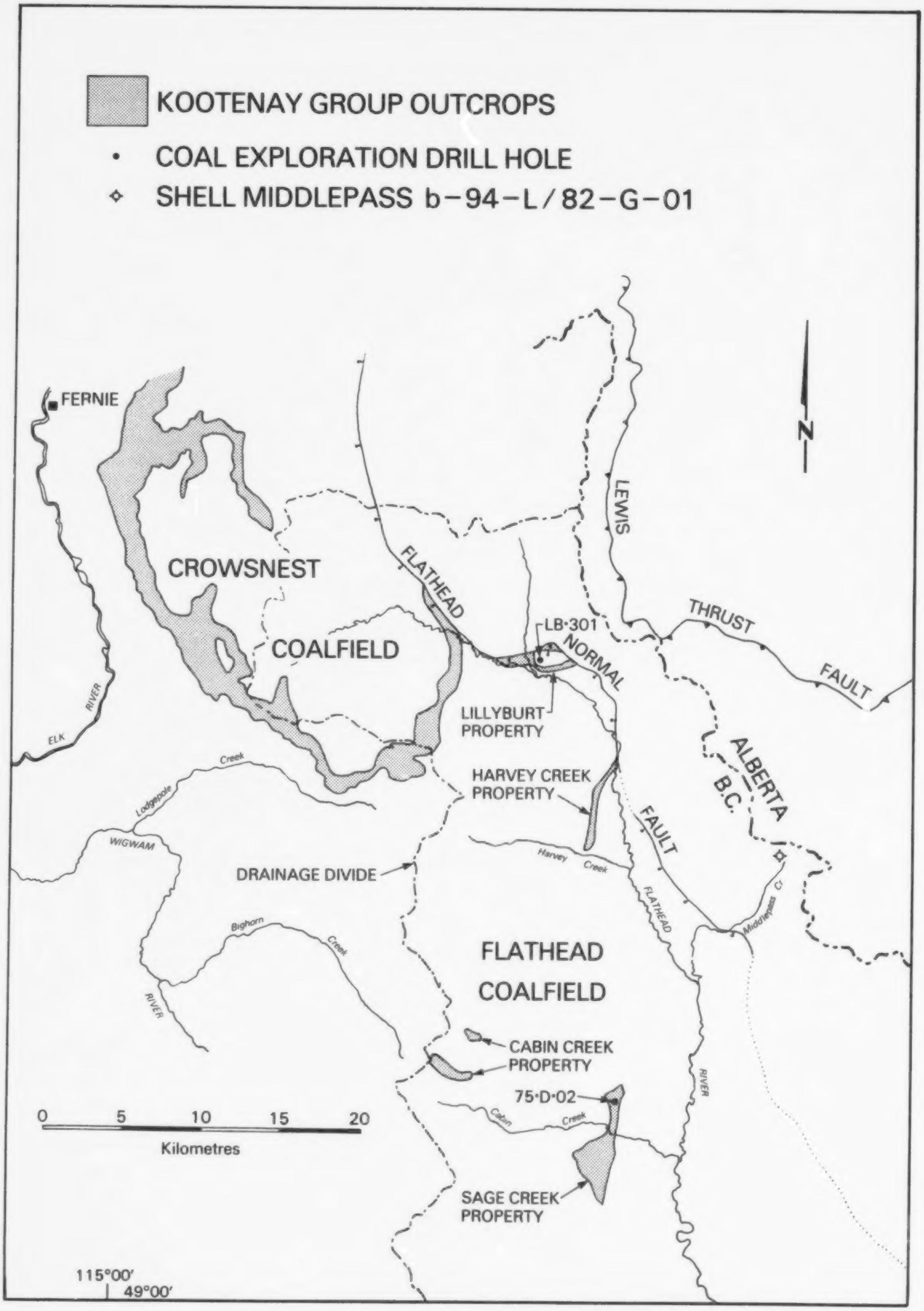
KOOTENAY GROUP OUTCROPS
• COAL EXPLORATION DRILL HOLE
◇ SHELL MIDDLEPASS b-94-L/82-G-01
FERNIE
CROWSNEST
COALFIELD
FLATHEAD
LEWIS
THRUST
FAULT
NORMAL
LB-301
LILLYBURT PROPERTY
HARVEY CREEK PROPERTY
FAULT
ALBERTA
B.C.
ELK
RIVER
Lodgepole
Creek
WIGWAM
DRAINAGE DIVIDE
Harvey
Creek
FLATHEAD
Middlepass Cr
Bighorn
Creek
RIVER
FLATHEAD
COALFIELD
CABIN CREEK PROPERTY
75-D-02
Cabin
Creek
RIVER
SAGE CREEK PROPERTY
0
5
10
15
20
Kilometres
N
115°00′
49°00′

Figure 5-3-1. Location map of Flathead Coalfield properties.

TABLE 5-3-1
COAL RANK DATA SUMMARY, FLATHEAD COALFIELD

Property	Range ($\bar{R}_o$ max) (Standard deviation)	Comments
Lillyburt	1.05–1.26 (.069) (.050)	Surface samples; lower part of Mist Mountain Formation not exposed; exact stratigraphic position of lowest $\bar{R}_o$ max value not known (upper Mist Mountain or Elk).
	1.11–1.30 (.041) (.049)	Drill hole LB-301; Mist Mountain and Elk Formations; *see* Figure 5-3-2.
Harvey Creek	1.33 (one sample) (.035)	Surface sample; exact stratigraphic position not known (lower Mist Mountain Formation).
Sage Creek (North Hill)	1.12–1.20 (.057) (.042)	Surface samples; Mist Mountain Formation; highest $\bar{R}_o$ max value corresponds with basal seam.
	1.03 (one sample) (.040)	Drill hole 75-D-02; 13 metres depth; Elk Formation.
Sage Creek (South Hill)	1.16–1.17 (.057) (.063)	Surface samples; Mist Mountain Formation; exact stratigraphic positions unknown.
Cabin Creek	1.17–1.22 (.048) (.033)	Surface samples; lower portion of Mist Mountain Formation; highest $\bar{R}_o$ max value corresponds with basal seam.
Shell Middlepass b-94-L/82-G-01 (below Lewis thrust)	1.11 (.047)	2475–2480 metres
	1.17 (.065)	2550–2555 metres*
	1.16 (.057)	2600–2605 metres*
		Base of Mist Mountain Formation at approximately 2537 metres.

* Possibly caved material.

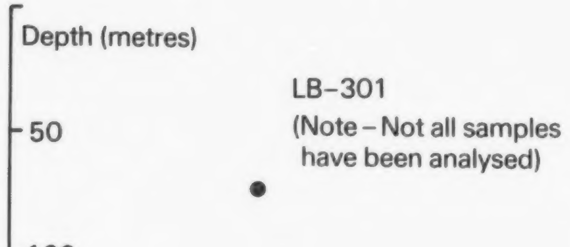

Figure 5-3-2. Reflectance-depth profile of drill hole LB-301.

CABIN CREEK

The two seams on the Cabin Creek property occur in the lower half of the Mist Mountain Formation. Samples analysed have reflectances of 1.17 to 1.22 per cent; the highest value represents a sample from the basal portion of the formation (Table 5-3-1).

MIDDLEPASS WELL

The three samples from below the Lewis thrust have reflectance values of 1.11, 1.17 and 1.16 per cent, increasing with depth (Table 5-3-1). The two deeper samples were apparently taken from below the base of the Mist Mountain Formation (Table 5-3-1), and thus possibly represent caved material.

DISCUSSION

Based on limited sampling, the majority of Mist Mountain Formation coals from the Flathead Coalfield are medium volatile bituminous, a somewhat lower rank than coals from the adjacent Crowsnest Coalfield (Pearson and Grieve, 1985).

Although the rank ranges for the four coal properties are not remarkably different, they can be divided into two groups. On average the Sage Creek and Cabin Creek properties have slightly lower rank coals than the Lillyburt and Harvey Creek properties. What, if any, influence proximity to the Flathead normal fault may have had on this contrast is not known.

The most intriguing results are from drill hole LB-301. They suggest that coal rank is independent of both stratigraphic position and present elevation, but the pronounced scatter of the data may be masking a more typical rank gradient. Possible reasons for scatter of this kind are discussed in another article in this volume.

Samples of Kootenay Group coals from beneath the Lewis thrust have rank values which are no higher than those found at the surface, despite the extra depth of burial represented by the thickness of the Lewis thrust sheet. This may imply that coalification was complete before thrusting took place. Alternatively, some post-thrusting enhancement of coal rank could have occurred if the coals below the Lewis thrust were previously at a lower rank than their counterparts in the Flathead Coalfield. This would imply a greater thickness of covering strata overlying the Mist Mountain Formation in the Flathead Coalfield. This does not seem unreasonable given the tens of kilometres of lateral distance which separated strata above and below the Lewis thrust prior to tectonic movements (for example, Bally *et al.*, 1966).

ACKNOWLEDGMENTS

Joanne Schwemler carried out all petrographic analyses. Crows Nest Resources Ltd. gave permission to sample core. Shell Canada provided samples from the Middlepass well, and gave permission to publish results. Interpretation of the data was aided by discussions with R.D. McMechan who together with F.R. Frey, reviewed an early version of the article.

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A GEOLOGICAL UPDATE OF THE CARBON CREEK AND BUTLER RIDGE AREAS*
(93O/15, 94B/1)

By A. Legun

INTRODUCTION

The area of study is located west of the W.A.C. Bennett Dam in northeastern British Columbia (Figure 5-4-1). Compilation and geologic mapping at a scale of 1:50 000 was initiated in 1982, focusing on coal geology, structure and Jurassic-Lower Cretaceous stratigraphy. One preliminary map has been published (Butler Ridge, 94B/1) and another (Carbon Creek, 93O/15) is pending.

Fieldwork in 1986 had three objectives:

(1) Mapping the west margin of the Carbon Creek syncline;
(2) Measuring a section of the Bickford Formation;
(3) Tracing Minnes Group stratigraphy eastward and resolving problems of correlation across the Carbon fault (*see* Legun, 1985b).

General geology will not be reviewed here. The reader is directed to previous reports (Legun, 1983, 1984, 1985a, 1985b, 1986) for a background of the structural geology and stratigraphy in the area, which are still undergoing revision. This paper presents an update which supersedes previous reports.

MINNES GROUP STRATIGRAPHY

Fieldwork at Mount Gething and examination of the Quasar *et al.* Dunlevy (a-40-L, 94B/1) lithology log suggests that a 50-metre interval of quartz arenite was correctly assigned to the Monteith Formation east of the Carbon fault and that an alternative assignment to the Monach Formation (interpretation 2 in Table 22-1 of Legun, 1985b) is incorrect.

With the top of the Monteith Formation correlated across the Carbon fault, the thickness of Minnes strata between the Monteith and Cadomin Formations can be shown to decrease from a maximum 990 metres in the West Carbon Creek area to 145 metres on the eastern slope of Butler Ridge (Table 5-4-1 and Figure 5-4-2). Thinning is dramatic in the area of Mount Gething where (barring hidden faults) the section is reduced from 370 to 225 metres over a distance of only 5 kilometres. Immediately west of the Carbon fault, Minnes strata above the Monteith Formation can be divided into the Beattie Peaks Formation shale, Monach Formation arenite, and

TABLE 5-4-1.
STRATIGRAPHIC THICKNESS DATA
(*See* Figure 5-4-2 for locations)

Area	Top of Monteith Formation to Base of Cadomin Formation (Metres)
(1) Eleven Mile Creek, south fork, head of valley	—
(2) Peak south of Mount Wrigley	990
(3) Carbon Lake	744
(Mount McAllister)	(650)
(4) Mount Gething	370
(South Mount Gething)	(225?)
(5) Quaser *et al.* Dunlevy a-40-L	210
(6) Butler Ridge	175
(7) Czar *et al.* Butler d-59-J	145

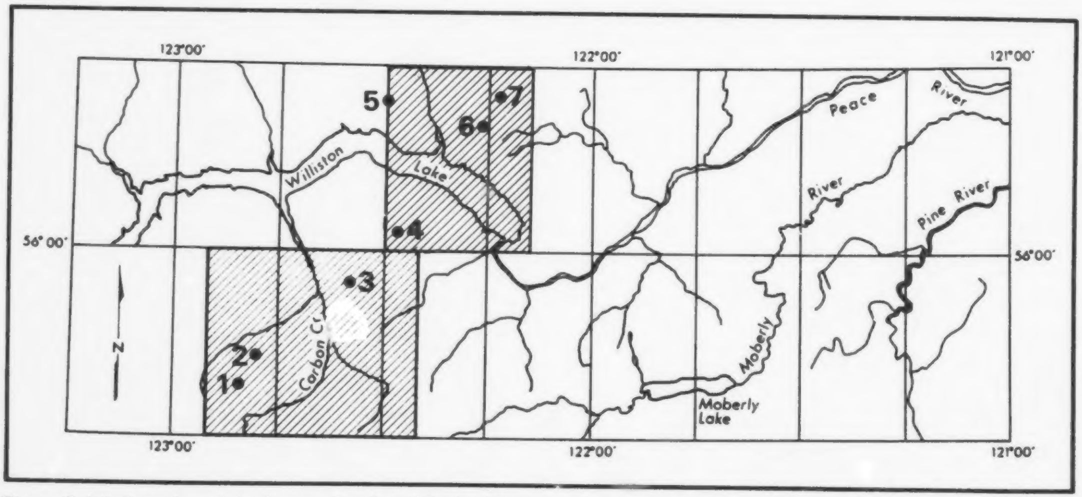

Figure 5-4-1. Location of the Carbon Creek and Butler Ridge map areas; stratigraphic thickness data at numbered locations (*see* Figure 5-4-2 and Table 5-4-1).

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

Bickford Formation interbedded arenite and shale. This lithostratigraphic subdivision cannot be made east of the fault. On Mount Gething, the section immediately above the Monteith quartz arenite consists of several shale to arenite cycles suggesting the Beattie Peaks Formation is shoaling (shaling out) to the east. Any overlying arenites of the Monach Formation cannot be lithologically separated from an arenaceous Beattie Peaks Formation. The writer has recognized facies typical of the Monach Formation (that is, low-angle crossbedded arenites) east of the Carbon fault (Legun, 1983) but the facies has proved to be discontinuous and it is uncertain whether the same stratigraphic interval is represented from one locality to the next. The entire sequence above the Monteith Formation east of the Carbon fault consists of interbedded arenites and siltstones with no persistent markers. As a whole the sequence crudely coarsens upward such that thick arenites often directly underlie the Cadomin Formation.

Since east of the Carbon fault the Minnes Group above the Monteith Formation undergoes facies changes and is not coherent laterally, the final map of the Butler Ridge area will only recognize an upper Minnes Group (undifferentiated).

BICKFORD FORMATION

A 290-metre section of the Bickford Formation was measured in the Carbon Creek area at the head of a valley just west of Mount Monach. The formation is well exposed on both limbs of a tight syncline. The section ends in the core of the syncline, without reaching the Cadomin Formation. The lower contact with the Monach Formation is placed at the transition from thick units of arenite to an interbedded sequence of arenite and shale. The arenite interbeds display swaley cross-stratification modified by wave-rippled (and variably burrowed) tops. The occasional arenite is intensely burrowed with packed single (*Skolithos*) or double (*Diplocreterion*) tubes. Upsection a quartz arenite is found followed by alternating beds of carbonaceous shale and rooted, current-rippled arenites. A change from shallow marine to beach to subaerial depositional environments is indicated.

RELATIONSHIP OF CADOMIN FORMATION TO UNDERLYING MINNES GROUP

The lithological contact of the Cadomin Formation with the underlying Minnes Group varies from gradational in the west to sharp in the east. The lithology immediately underlying the lowest pebbly arenite varies from carbonaceous arenites and thin coals (gradational contact) to burrowed marine siltstone (sharp contact) to quartzitic and/or noncarbonaceous arenites (sharp contact).

Detailed fieldwork suggests the Cadomin Formation lies at a different stratigraphic level from locality to locality. At Mount Gething the basal pebbly arenite is replaced by stratigraphically

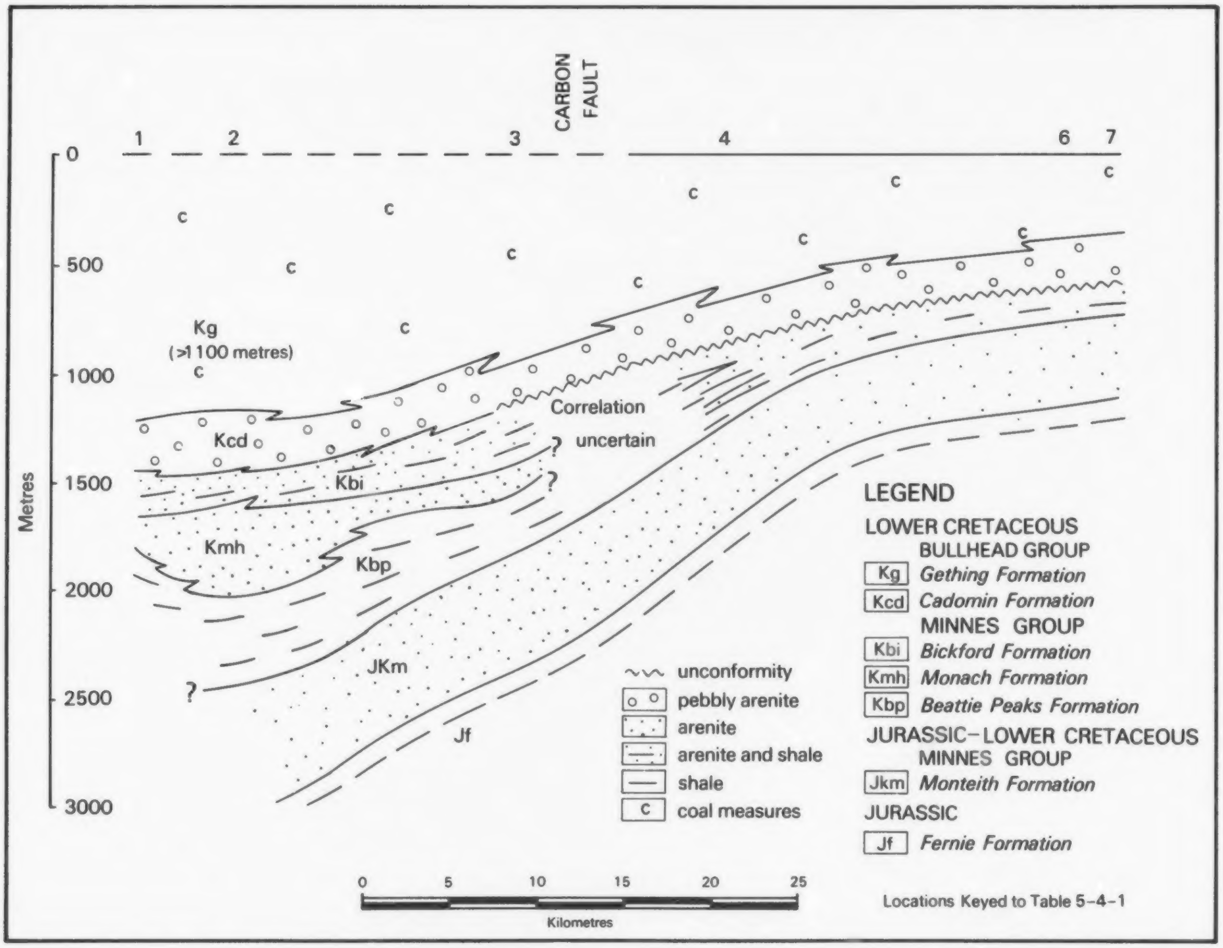
CARBON FAULT
1
2
3
4
6
7
Metres
0
500
1000
1500
2000
2500
3000
Kg
(>1100 metres)
Kcd
Kbi
Kmh
Kbp
JKm
Jf
Correlation
? uncertain
?
?
c
LEGEND
LOWER CRETACEOUS
BULLHEAD GROUP
Kg Gething Formation
Kcd Cadomin Formation
MINNES GROUP
Kbi Bickford Formation
Kmh Monach Formation
Kbp Beattie Peaks Formation
JURASSIC–LOWER CRETACEOUS
MINNES GROUP
Jkm Monteith Formation
JURASSIC
Jf Fernie Formation
unconformity
pebbly arenite
arenite
arenite and shale
shale
c coal measures
0
5
10
15
20
25
Kilometres
Locations Keyed to Table 5-4-1

Figure 5-4-2. Generalized southeast-northwest stratigraphic section of Jurassic-Lower Cretaceous Formations (*see* Figure 5-4-1 for locations).

lower pebbly arenites along strike. At Mount Wrigley careful tracing of marker units on airphotos shows basal pebbly arenites of the Cadomin Formation lie on strike with interbedded arenites and shales of the Bickford Formation.

Biostratigraphic evidence for a regional unconformity at the base of the Cadomin Formation has been documented by Stott (1973) and Broatch (1986). Stott considers the Cadomin Formation to rest on Beattie Peaks Formation strata at Bullhead Mountain. Legun (1983) considered it to rest on the Monach Formation, but has subsequently (this paper) decided that the Minnes Group is not subdivisible east of the Carbon fault due to facies changes at the hinge line of the depositional basin at Mount Gething (Figure 5-4-2). The question of what proportion of the Minnes Group has been eroded, and what proportion has thinned out by onlap onto the basin margin, can only be resolved by biostratigraphic comparison of the Minnes succession at Carbon Creek and Bullhead Mountain.

GEOLOGIC MAPPING

Additional fault and fold structures complicate the trace of geologic map units on the west margin of the Carbon syncline as presented in Legun (1985b, Figure 22-3). These include north-plunging folds in the area of Cadomin Formation exposure at Eleven Mile Creek and fault repeats of the Monach and Bickford Formations immediately north of Mount Monach. Map units were also redefined east of Mount Cowper and east of the Beattie Peaks, as a result of creek traverses. The extension of the Canfor road up the Carbon Creek watershed was also mapped.

In the Butler Ridge map area a major fault on the south face of Mount Gething was redefined (*see* section C-D in Legun 1985a). Near surface, at the peak, the fault is more shallow-dipping than previously thought (25 degree dip) and steeper (subvertical) at depth, as exposed on the lower slopes. Hangingwall strata form a box anticline with the east limb cut off by the fault. Formation of the box anticline is probably related to the fault ramp below. The traces of the Monteith and Cadomin Formations were carefully remapped on Mount Gething, allowing thickness compilation of the Monteith to Cadomin Formation interval (*see* Minnes Group Stratigraphy).

FUTURE WORK

No further fieldwork is contemplated.

ACKNOWLEDGMENTS

George Walker provided cheerful and willing assistance in the field.

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RELATION OF GETHING FORMATION COAL MEASURES TO MARINE PALEOSHORELINES*

(93P, 93I)

By A. Legun

INTRODUCTION

In a recent correlation of Lower Cretaceous coalmeasures in the Peace River Coalfield, Duff and Gilchrist (1983) documented the presence of a major marine tongue in the Gething Formation. It separates the Gething Formation into upper and lower coal-bearing members over an area extending southeastward from the Sukunka River. Northwest of the Sukunka River the upper coal measures pinch out and the marine tongue passes laterally into the Moosebar Formation. To the southeast, at Kinuseo Creek, the marine tongue pinches out and upper and lower coal measures merge. The upper coal measures of the Gething Formation are termed Chamberlain Member by Duff and Gilchrist (1983).

The author has evaluated the subsurface extent of the continental Chamberlain Member into the plains, by an examination of oil and gas well logs (Legun, 1985). The loss of a coal facies between one well and the next was equated with crossing the continental/marine boundary. The trace of the boundary (paleoshoreline) defined the presence of two subaerial deltas in the vicinity of Gwillim Lake and South Kiskatinaw River respectively (Figure 5-5-1 and Table 5.5.1).

Other work related to this study includes Kilby (1985) on correlation of tonsteins immediately above the Chamberlain Member, Oppelt (1986) on the sedimentology of the Bluesky Formation (Gething marine tongue equivalent), and Smith *et al*. (1984) on paleogeography of the Bluesky and Gething Formations.

AIMS

The aims of the present study are:

(1) Locate all coal and petroleum boreholes that intersect the upper and middle Gething members;

(2) Establish major lines of section and correlation;

(3) Identify coal-bearing intervals of economic interest in the Gething Formation;

(4) Determine depositional environments in the Chamberlain Member;

(5) Determine the relationship between coal thickness trends and the paleoshoreline.

1986 WORK

Work in 1986 consisted of filing logs from over 200 boreholes that intersected the upper and middle Gething members (with some overlap to the lower Gething member). Locations were plotted on a 1:100 000 base map and selective logs were reduced to a 1:600 scale for correlation. Albert Terry, summer assistant, began compilation of coal thickness data from each borehole location. Two field sections were measured near Mount Reesor.

PRELIMINARY RESULTS

Initial results are discussed in the context of two lines of section, parallel and perpendicular to the trend of the foothills (Figures 5-5-2 and 5-5-3).

UPPER GETHING FORMATION (CHAMBERLAIN MEMBER)

The Chamberlain Member maintains a thickness of 40 to 60 metres along the foothills trend from the Sukunka River to Babcock Creek. Southeast of Babcock Creek it thins to 20 metres or less. Perpendicular to the foothills trend, the Chamberlain Member thickens from 0 metre in the plains (northeast of the line of section) to 60 metres or more in the foothills. In the westernmost exposures of the member at Mount Reesor up to 90 metres may be present.

A marine interval within the Chamberlain Member has been documented northwest of the Wolverine River by Duff and Gilchrist (1983). An upward coarsening sequence is noted on geophysical logs. The marine interval separates the Skeeter and Chamberlain seams from the Bird seam above. This marine interval apparently pinches out to the southeast, near QWD7115, and is replaced by upward fining sequences interpreted as deposits of delta distributaries or fluvial channels.

The Bird seam lies at or just below the Moosebar-Gething Formation contact in the foothills. Additional continental strata may lie

TABLE 5-5-1
LINE OF SECTION LOCATIONS
(SEE FIGURE 5-5-1)

Location No.	**Oil and Gas Wells**
(1)	Dome PCI Sukunka (d-55-A/93-P-15)
(10)	BP *et al* Murray (b-92-J/93-I-14)
(13)	Oakwood *et al* Murray (d-99-E/93-I-15)
(14)	Quasar *et al* Murray (a-89-E/93-I-15)
(17)	Texaco Flatbed (a-21-F/93-I-15)
(21)	Quasar Mobil Flatbed (d-57-D/93-P-2)
(22)	Quasar Mobil Flatbed (d-76-D/93-P-2)
(23)	Canhunter Tumbler (c-40-F/93-P-2)
	Measured Section
(16)	Stott 59-10
	Coal Boreholes
(2)	Sukunka SK 1
(3)	Sukunka BP 53
(4)	Sukunka C 35
(5)	Sukunka BP 6
(6)	Mount Spieker MS 1
(7)	Quintette QWD 7115
(8)	Quintette WDH 1
(9)	Quintette QMR 8122
(11)	Quintette QBR 8121
(12)	Quintette QBD 7102
(15)	Quintette QBD 7403
(18)	Monkman MDH 7807
(19)	Quintette QFD 7220
(20)	Quintette QBD 8106

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

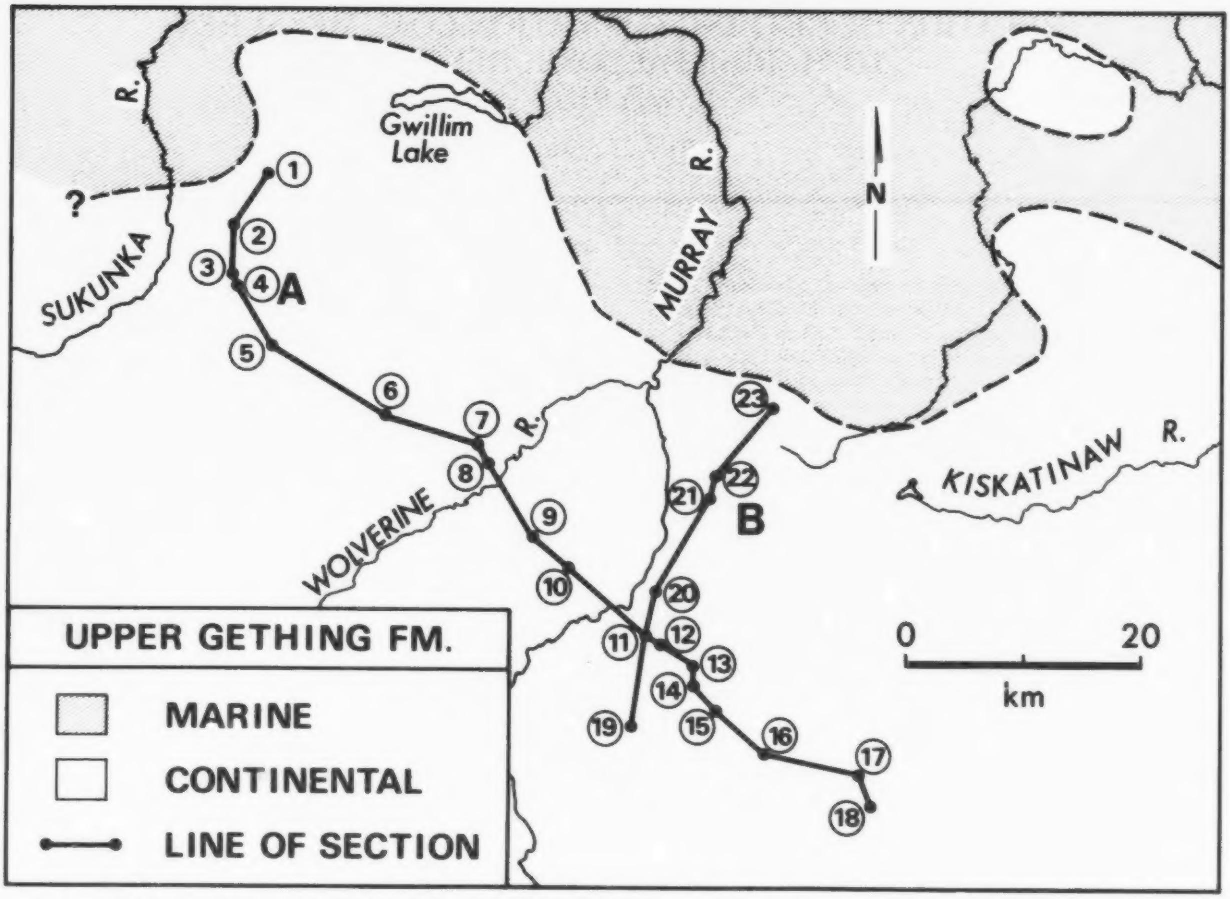
SUKUNKA R.
?
Gwillim Lake
MURRAY R.
N
A
B
WOLVERINE R.
KISKATINAW R.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
0
20
km
UPPER GETHING FM.
MARINE
CONTINENTAL
LINE OF SECTION

Figure 5-5-1. Study area with locations of two lines of borehole sections. Dashed line marks approximate limits of continental Chamberlain Member beds. Hole identifications are given in Table 5.5.1.

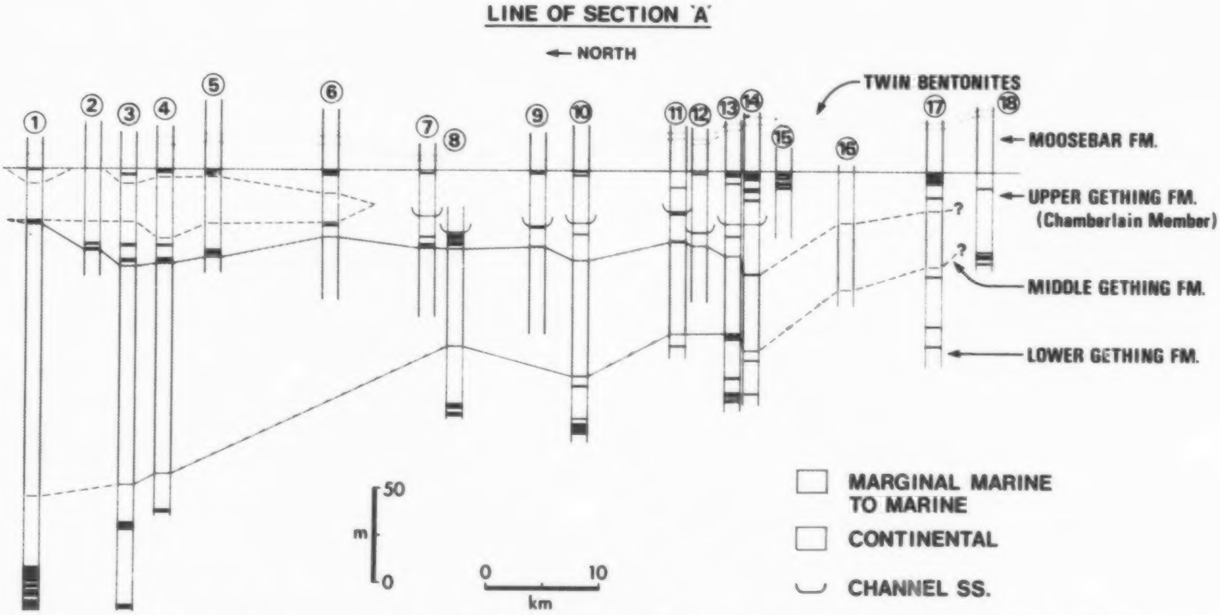
LINE OF SECTION 'A'
← NORTH
TWIN BENTONITES
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
← MOOSEBAR FM.
← UPPER GETHING FM. (Chamberlain Member)
?
?
MIDDLE GETHING FM.
← LOWER GETHING FM.
50
m
0
0
10
km
MARGINAL MARINE TO MARINE
CONTINENTAL
CHANNEL SS.

Figure 5-5-2. Section A oriented parallel to the present structural trend of the study area. Major coal seams are shown in black.

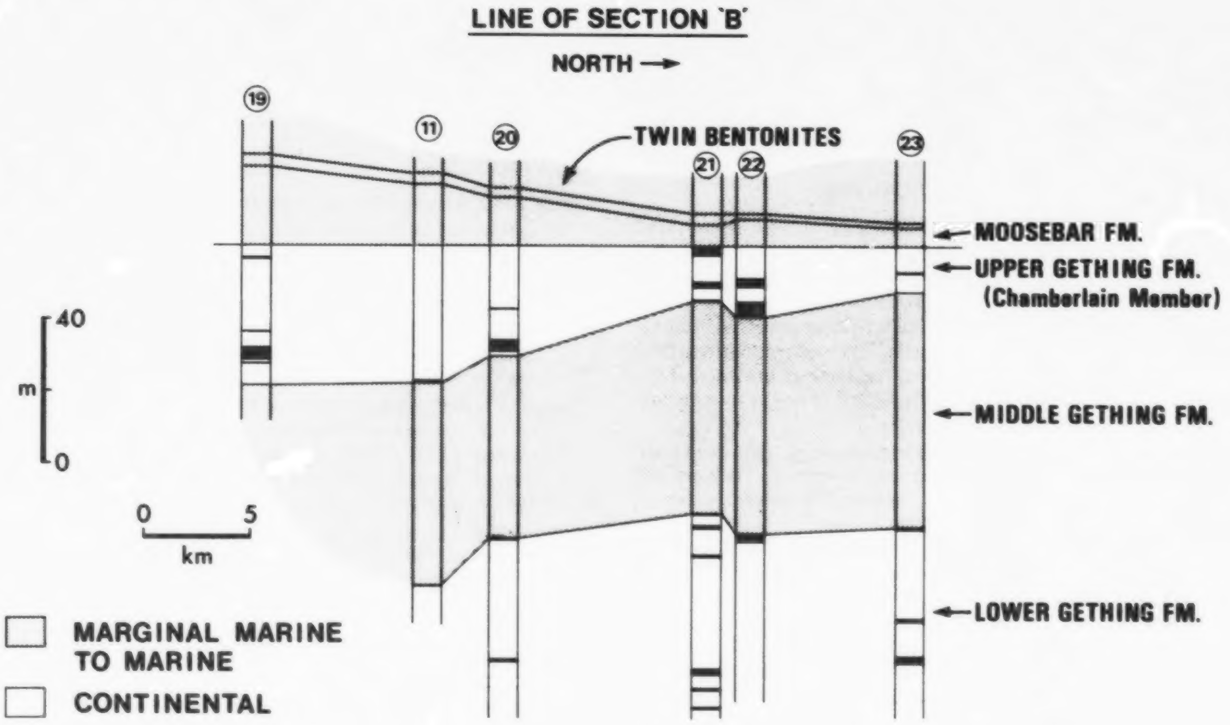

Figure 5-5-3. Section B oriented normal to regional structural trend. Note thinning in Chamberlain Member to east. Major coal seams shown in black.

between the Bird and the Moosebar Formations in westernmost exposures (west flank of Mount Reesor, Saddle Creek). The seam can be traced to the southeast to near Kinuseo Creek, but is missing in the area of QBRB121 and QBD8106 near the Murray River.

The Chamberlain seam is recognized as the first coal above the deposits of the middle Gething marine regression. To the northwest it is the last coal seam in the member to pinch out against marine strata. To the southeast it becomes thin and impersistent across the Wolverine River.

The Skeeter seam lies above the Chamberlain seam and is usually separated from it by 10 metres or less. The Skeeter is thin and impersistent southeast of the Wolverine River.

Thickness trends have not yet been evaluated for these seams but in the Sukunka deposit the Chamberlain is occasionally 5 metres or more thick with the Bird and Skeeter rarely exceeding 2.5 metres.

MIDDLE GETHING FORMATION (GETHING MARINE TONGUE)

The middle Gething Formation is noncoal-bearing and typified on geophysical logs by an upward coarsening trend (gamma ray curves to left upsection), with or without a sandstone unit (gamma ray blocky profile) at the base. Duff and Gilchrist (1983) recognized a brackish to marine fauna in the middle Gething Formation. In the line of section, the middle Gething Formation thins from 145 metres in the northwest to 30 metres in the southeast where it is last recognized on gamma log in the Texaco Flatbed well (a-21-F, NTS 93I/15). South of there it is not present in the foothills but is present in the plains region to the east, indicating the southern shoreline of the marine tongue crosses the line of section near MDH7807.

Oppelt (1986) shows the marine tongue present in the foothills as far south as the Wapiti River. This writer considers his southward correlation to MDD7804 to be incorrect. The designated interval in MDD7804 correlates below the middle Gething Formation in the Texaco Flatbed well. Oppelt should reconsider the correlation in light of the geophysical log for this well. Oppelt's correlation results in the Chamberlain Member thickening to the southeast and resting almost directly on the Cadomin Formation.

The middle Gething Formation consists of transgressive and regressive deposits. The basal sandstone unit [Bluesky facies C of Oppelt (1986), Williams (1984)] is interpreted by this writer as reworked coastal or delta margin sands (destructional facies) deposited during the initial transgression. The actual coarsening-up cycle [Bluesky facies B of Oppelt (1986), Williams (1984)] represents deposits of the regression. At Mount Reesor (outside the line of section) there is abundant evidence of storm wave deposits (swaley and hummocky cross-stratification) in this interval.

LOWER GETHING FORMATION

The lower Gething coal measures lie above the pebbly arenites of the Cadomin Formation and below the basal sandstone unit of the Gething marine tongue. Though the coals of the lower Gething Formation were not the focus of this study, significant intervals of coal were found in the member in the course of borehole correlation. This includes a possible 17 metres of coal, over 25 metres of section, in the Dome PCI Sukunka well (d-55-A, NTS 93P/5). The coal interval may be equivalent to the lower zone in BRE 5 (Burnt River East property) consisting of 15 metres of carbonaceous to coaly mudstone and minor coal. Also significant are seams GT1 and GT2 on Quintette's Hermann Gething property near well BP *et al* Murray (b-92-J, NTS 93I/14). These seams are 45 metres below the base of the marine tongue and comprise 5 to 6 metres of cumulative coal.

The lower Gething coal measures have been the subject of little exploration activity except on the Teck Corp. Burnt River property to the north, where seams reach 8 to 9 metres in thickness. Economic potential is postulated to slowly decrease southeastward from the Burnt River toward Kinuseo Creek in line with the increasing alluvial (conglomeratic) character of the lower Gething Formation.

DISCUSSION AND CONCLUSIONS

The lower Gething Formation represents alluvial deposits and contains coals of economic significance that have been insufficiently evaluated to date. The lower Gething is overlain by deposits of the middle Gething marine transgression and regression.

The southern shoreline of the middle Gething marine embayment is near Kinuseo Creek in the foothills. The western shoreline is in eroded terrain west of the foothills. The southern extension of the embayment to the Wapiti River by Oppelt (1986) is in error and based on a miscorrelation.

The upper Gething Formation (Chamberlain Member) represents subaerial deposits of a sedimentary wedge (molasse) that extends from the Sukunka River in the northwest to Kinuseo Creek or further in the southeast. North of the Sukunka River the shoreline swings sharply to the west and lies in presently eroded terrain west of the foothills. South of the Sukunka River the shoreline lies east of the foothills and is marked by two delta lobes.

The axis of these delta lobes swings to the northwest suggesting dispersal of sand parallel to the axis of the basin. This has been shown to be true for many Late Jurassic and Cretaceous units (Taylor and Walker, 1984). Such a process of sediment dispersal will result in lateral linkage of delta lobes at the seaward edge and the confinement of large interdeltaic lakes on the landward side. The lakes would be suitable environments for the formation of thick and laterally extensive peats. It is postulated that the coals of the Gething Chamberlain Member (as well as the coals of the Gates Formation) formed in such environments.

ACKNOWLEDGMENTS

My thanks go to Dave Hughes of the Institute of Sedimentary and Petroleum Geology for providing the database for the Sukunka deposit and to Dave Johnson, Ministry of Energy, Mines and Petroleum Resources for oil and gas well listings. Albert Terry provided cheerful assistance in the office and George Walker was willing and able in the field.

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BULLMOOSE MAPPING AND COMPILATION PROJECT*
(93P/3, 4)

By W. E. Kilby and C. B. Wrightson

INTRODUCTION

The Bullmoose mapping and geological compilation project is an amalgamation of several existing projects utilizing data from various sources. The objective is to compile 1:50 000-scale geological maps for NTS map sheets 93P/3 and 93P/4. Semi-automated techniques were used for data handling, interpretation and presentation. Open file geology maps will be produced and existing data from all available sources compiled into computer processable format for distribution. This initial project will test the applicability of microcomputer-aided geological analysis on a regional scale. Work is ongoing with final products nearing completion; this review will focus on the data and techniques utilized during the project.

LOCATION

The map area is located in the heart of the Northeast British Columbia coal development and includes the pit areas of both the Quintette and Bullmoose operations. The area encompasses some 1640 square kilometres and lies mainly within the inner and outer foothills physiographic regions. The southwest corner of the study area covers a portion of the main and front ranges of the Rocky Mountains and this geology is not addressed.

Elevations vary from 730 metres to 1980 metres. Three major river systems drain the area: Sukunka, Wolverine and Murray. In general these waterways cut across the northwest-trending regional geological strike (Figure 5-6-1). The orientation of these water courses is controlled by Pleistocene glaciation which resulted in classic U-shaped valleys and cirque topography. Vegetation varies from alpine tundra to pine and spruce forests which are the basis of a significant forestry industry.

Access consists of one paved provincial highway (No. 29), several major forestry access roads, the Tumbler Ridge branchline of British Columbia Railway and numerous coal company access roads. The new town of Tumbler Ridge is located just off the eastern edge of the map area.

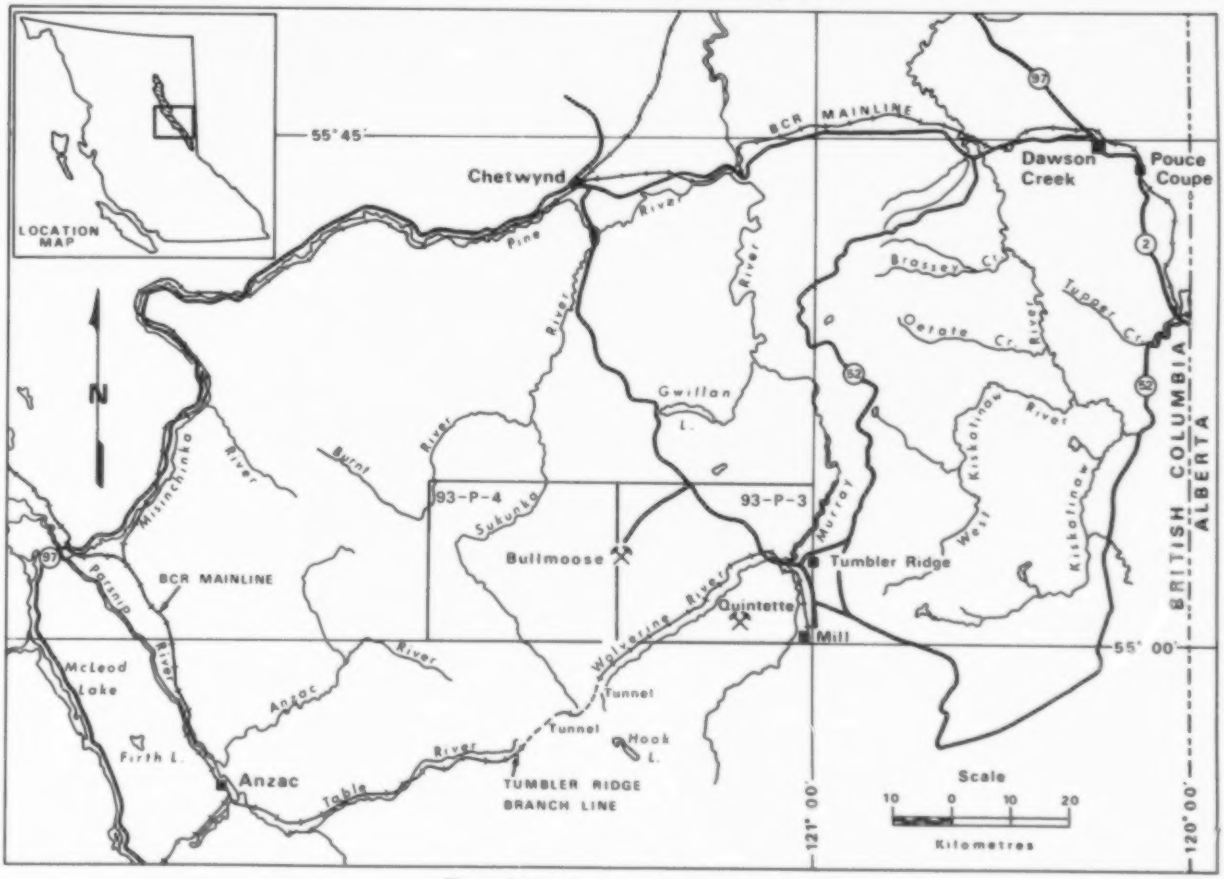
LOCATION MAP
55°45'
Chetwynd
BCR MAINLINE
97
Dawson Creek
Pouce Coupe
Pine
River
River
2
Brassey Cr.
Tupper Cr.
Oetata Cr.
River
52
Gwillan L.
Kiskatinaw River
West
Kiskatinaw
N
Misinchinka
River
Burnt
River
93-P-4
93-P-3
Sukunka
Murray
Bullmoose
Tumbler Ridge
97
Parsnip
BCR MAINLINE
River
Wolverine
River
Quintette
Mill
55° 00'
McLeod Lake
River
Anzac
Tunnel
Tunnel
Hook L.
Firth L.
River
Anzac
Table
TUMBLER RIDGE BRANCH LINE
121° 00'
Scale
10 0 10 20
Kilometres
120° 00'
BRITISH COLUMBIA
ALBERTA

Figure 5-6-1. Study area location map.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

STRATIGRAPHY

The stratigraphy of the area has been investigated and described by numerous workers, most notably D.F. Stott (1968, 1973, 1982). Rocks ranging in age from Devonian to Late Cretaceous are exposed in the area. This study concentrated on rocks of the Jurassic Minnes Group and Cretaceous Bullhead and Fort St. John Groups. The general depositional history has been well described by previous authors and is beyond the scope of this report. The formation names and general characteristics, including approximate thicknesses, are summarized in Figure 5-6-2. Coal measures of economic interest are found within both the Gething and Gates Formations of the Bullhead and Fort St. John Groups respectively. Current production in the Peace River Coalfield is limited to Gates Formation rocks. Minor coals are also found in the Upper Minnes Group and the Cadomin and Boulder Creek Formations.

MINNES GROUP

The Minnes Group comprises in excess of 1800 metres of interbedded sandstone, shale, siltstone and minor coal. Further north it has been subdivided into four formations. Complex structural geology and the absence of readily mappable units have prevented subdivision of the Minnes Group in this map area.

The Minnes Group is unconformably overlain by the Cadomin Formation of the Bullhead Group.

BULLHEAD GROUP

CADOMIN FORMATION

The Cadomin Formation is a resistant conglomerate unit. It commonly consists of three prominent conglomerate bands with interbeds of more recessive sandstone. The upper and lower contacts of the formation are abrupt and easily identifiable in the field.

SERIES	GROUP	FORMATION	THICKNESS IN METRES	LITHOLOGY
UPPER CRETACEOUS	SMOKY	KASKAPAU	~ 440+	Dark grey marine rubbly shale with sideritic concretions and sandstone
		DUNVEGAN	~ 475	Marine and non-marine sandstone and shale
	FORT ST. JOHN	CRUISER	~ 110	Dark grey marine shale with sideritic concretions, some sandstone
LOWER CRETACEOUS		GOODRICH	~ 50	Fine-grained, crossbedded sandstone; shale and mudstone
		HASLER	~ 250	Silty, dark grey marine shale with sideritic concretions; siltstone and sandstone in lower part, minor conglomerate
		BOULDER CREEK	~ 120	Fine-grained, well sorted sandstone; massive conglomerate; non-marine sandstone and mudstone
		HULCROSS	~ 100	Dark grey marine shale with sideritic concretions
		GATES	~ 130	Fine-grained, marine and non-marine sandstones; conglomerate; coal; shale and mudstone
		MOOSEBAR	~ 130	Dark grey marine shale with sideritic concretions, glauconitic sandstone and pebbles at base
	BULLHEAD	GETHING	~ 375	Fine- to coarse-grained, brown, calcareous, carbonaceous sandstone; coal, carbonaceous shale, and conglomerate
		CADOMIN	~ 40	Massive conglomerate containing chert and quartzite pebbles
	MINNES	UNDIFFERENTIATED	~1700	Thinly-thickly interbedded shale, sandstone, siltstone and coals
JURASSIC		FERNIE	~ 700	Black marine shale

Figure 5-6-2. Stratigraphic framework (modified after Stott, 1983).

GETHING FORMATION

The Gething Formation is a coal-bearing deltaic unit predominantly nonmarine, but including significant marine trangressive-regressive intervals. A large marine tongue which thins to the south has been referred to as the middle Gething. Coal seams in the upper Gething, Chamberlain Member, have been extensively evaluated on the Sukunka property and coals in the lower Gething have been investigated north of the Sukunka River toward the Peace River.

FORT ST. JOHN GROUP

MOOSEBAR FORMATION

The marine Moosebar Formation lies between the Gething and Gates Formations. The lower portion of this formation is massive black mudstone. Above this a series of upward-coarsening cycles culminates in a clean beach sandstone. This upper portion of the Moosebar is known as the Torrens Member. The lower contact of the Moosebar is usually marked by a thin lag conglomerate with associated glauconite occurrences. This glauconitic unit has been referred to as the Bluesky equivalent, but this reference is abandoned in this study due to the problem of which of two units do in fact correlate with the Bluesky Formation of the subsurface. A glauconite-rich zone with an associated lag conglomerate also occurs at the base of the middle Gething marine tongue. This horizon correlates with the Gething-Moosebar contact in the Pine and Peace River areas.

GATES FORMATION

Studies of the Gates Formation by Leckie and Walker (1982) and Carmichael (1983) have shown that the shoreline during this time was oriented approximately east-west and fluctuated across the map area. Coals in the Gates Formation become thinner and less frequent a short distance to the north, due to persistent marine conditions. In the map area coals in this formation are being exploited by Quintette Coal Mines Ltd. and Bullmoose Operating Corp. To the south the Gates Formation and equivalent formations extend as far as the North Saskatchewan River in Alberta.

HULCROSS FORMATION

The Hulcross Formation is a marine shale unit overlying the Gates Formation. Locally a thin conglomerate bed marks the lower contact.

BOULDER CREEK FORMATION

The Boulder Creek Formation overlays the Hulcross Formation and consists of resistant weathering conglomerate and sandstone strata.

SHAFTESBURY FORMATION

The sequence of Hasler-Goodrich-Cruiser Formations is commonly referred to as the Shaftesbury Formation to the south of the map area and in the subsurface of the plains. This name change is dependent upon the presence or absence of the Goodrich Formation. The Goodrich is a sandstone unit which pinches out in the southern portion of the map area. The Hasler and Cruiser Formations are dark marine mudstone units with few distinguishing features.

SMOKY GROUP

DUNVEGAN FORMATION

The Dunvegan Formation is a marine to nonmarine unit with fluvial sand channels superimposed on thinly bedded mudstone and siltstone strata. The sandstone channels often form discontinuous sandstone ridges on hillsides.

KASKAPAU FORMATION

This marine shale formation outcrops in the eastern portions of the map area. It is generally recessive and forms large grassy slopes if capped by a resistant sandstone unit.

DATA

Efficient handling of data is one of the major objectives of this project. Existing data from geological maps and well logs were collected and stored in a processable form. Newly acquired mapping data were quickly added to existing information to provide a database for analysis.

Existing outcrop information was collected from assessment reports submitted on properties located in the study area. The following information was recorded for each outcrop location using a digitizing tablet and microcomputer:

- Outcrop identification,
- Outcrop UTM coordinates,
- Outcrop elevation,
- Formation,
- Structure type,
- Structure dip direction or trend,
- Structure dip or plunge.

A significant portion of the outcrop data was collected by contract personnel under the Canada/British Columbia Coal Data Acquisition Program.

Coal company borehole information was available from the Ministry of Energy, Mines and Petroleum Resources computer-based COALFILE database and hard-copy reports on file with the Ministry. Location and identification data were readily available in machine processable form. Analysis of the borehole data required manual interpretation of the hard-copy logs.

Oil and gas well logs were reviewed and interpreted at the Ministry's facilities in Victoria. Formation and marker contacts were recorded and provided much needed deep subsurface control.

Surface formation contacts and fault lines were digitized from assessment report maps to facilitate interpretation in the field.

Topographic data for the map area were taken from 1:50 000-scale National Topographic System maps. A digitizing tablet and microcomputer were used to collect the data which were then stored as a network of elevation points. Figure 5-6-3 displays these data in a three dimensional format.

A large amount of information was available in addition to data collected this field season. The complete database included: 7667 outcrop stations, 660 coal company boreholes, 15 oil and gas wells, and 6731 topographic points on 500-metre centres.

Examination of the data quickly showed which areas required close scrutiny and where additional fieldwork would be redundant.

In the field, outcrop data collected during traverses were entered periodically into the microcomputer system. The ability to enter data in the field reduces entry errors due to the time lag and elevates the power of computer analysis from an after-thought process to an interactive field geology tool.

HARDWARE, SOFTWARE AND TECHNIQUES

HARDWARE

A variety of computer hardware components were utilized during the project. A GTCO digitizing tablet connected to an IBM XT provided the digitizing capability used to record outcrop data, formation and structure trace location information, and topographic data. Analysis and data maintanence were performed on a Comtex IBM-compatible computer with an Epson FX 80 printer and Roland DXY 800 plotter as peripheral devices. A larger format Houston Instrument DMP-42 plotter was employed during the final analysis stage.

SOFTWARE

Digitizing software was written by Ward Kilby with data storage made compatible with the Geological Analysis Package of Cal Data Ltd. The Geological Analysis Package was used for all phases of data storage, manipulation and presentation. File management was performed with the Data Handler module; structural analysis and

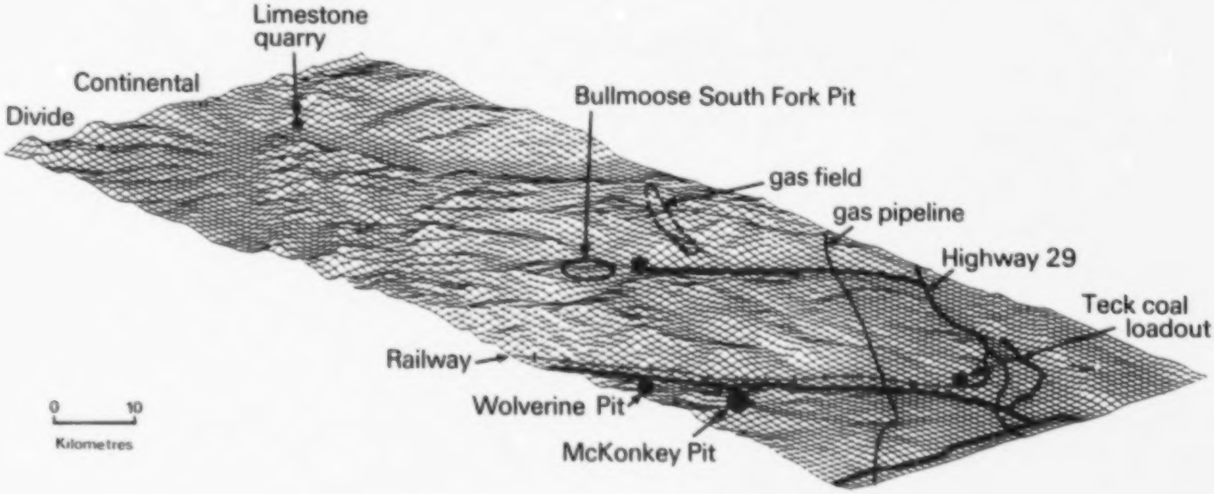

Figure 5-6-3. Isometric view of study area topography, showing location of infrastructure and major developments.

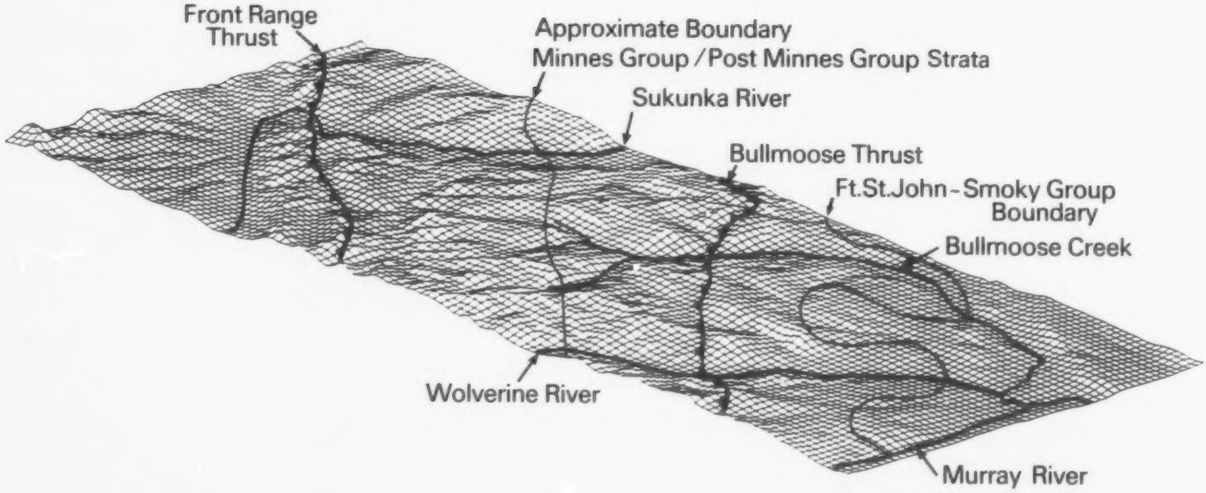
Front Range Thrust
Approximate Boundary Minnes Group / Post Minnes Group Strata
Sukunka River
Bullmoose Thrust
Ft.St.John - Smoky Group Boundary
Bullmoose Creek
Wolverine River
Murray River

Figure 5-6-4. Surface traces of the Front Range and Bullmoose fault zones. Also noted is the approximate location of the trace of the upper contact of the Minnes Group and the Fort St. John-Smoky Group contact.

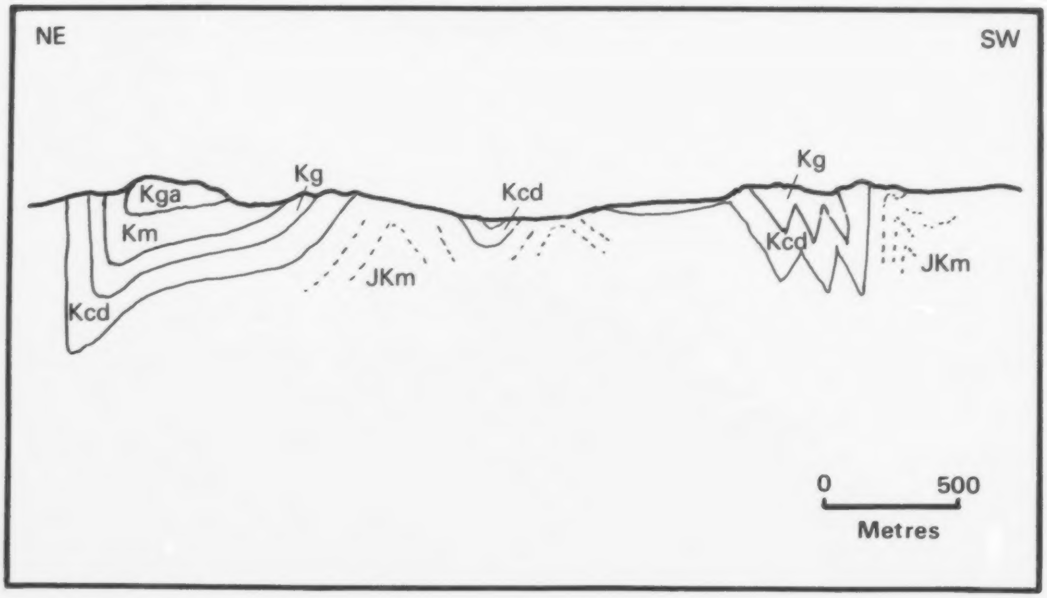
NE
SW
Kga
Kg
Km
Kcd
JKm
Kcd
Kg
Kcd
JKm
0
500
Metres

Figure 5-6-5. Line trace drawing from photographs illustrating the structural style in the Mount Reesor area.

data presentation functions were performed with the Structural Analysis module and surface modelling functions utilized the Grid Handler module.

Computer-based structural analysis techniques have been used throughout the coal-bearing regions of the Cordillera (Kilby, 1978; Langeberg, 1985; Wrightson, 1978). These techniques have been taught in short courses and undergraduate structural geology courses for more than a decade (Charlesworth *et al.*, 1976), but it has been the advent of the microcomputer which has made their field application possible.

STRUCTURE

The structural features of the study area have been described by numerous company and government geologists. Regional maps (1:250 000 and 1:500 000) have been produced by Stott (1968 and 1982). More detailed property mapping programs are described in numerous coal and petroleum assessment reports on file with the Ministry of Energy, Mines and Petroleum Resources.

The prominent structures are northwest-striking folds and thrust faults. Two major thrusts cut the area; the Front Range fault brings Paleozoic strata to the surface and marks the eastern edge of the Rocky Mountains. Further to the east the Bullmoose fault zone is the only major thrust fault to affect the surface exposures of the coal-bearing strata. The surface traces of these two faults are roughly parallel. The Front range fault dips steeply to the southwest. The Bullmoose fault also dips to the southwest, but is much shallower as suggested by its surface trace (Figure 5-6-4). There are undoubtedly blind thrust faults present in the map area but in the coal measures they are expressed as folding in the strata.

The structural geology of the area varies from relatively simple to complex. In general structures tend to become broader both in an eastward direction and up-section. The alternation of relatively competent and incompetent units, nonmarine and marine, tends to result in variable styles of deformation within the same structure. Very tight structures commonly visible in the Cadomin Formation are completely unrecognizable in the Gates Formation, due to disharmonic deformation in the intervening incompetent Moosebar Formation. Figures 5-6-5 and 5-6-6 illustrate some of the structural styles seen in the area.

ECONOMIC GEOLOGY

Two coal-bearing formations, the Gates and Gething, have attracted considerable exploration attention. At present two mining operations are exploiting the coal measures of the Gates Formation. Quintette Coal Mines Ltd. is producing 4.75 million tonnes of clean metallurgical product and 650 000 tonnes of thermal product per year. The Bullmoose Operating Corp. is producing 1.7 million tonnes of metallurgical coal annually.

Oil and gas exploration has resulted in the discovery of economic gas pools. Production from these wells is approximately 36 040 000 cubic metres per year, moved to market through the Grizzly Valley pipeline of Westcoast Transmission Ltd.

CONCLUSION

The Bullmoose project has successfully utilized large quantities of structural data from various sources to compile a regional geological interpretation. The application of computer-based techniques has proven useful and in fact may be essential. The project will meet its primary goal of providing 1:50 000 mapping coverage of the coal measures and adjacent strata of 93P/3 and 93P/4 map sheets. In addition the collection and filing of most available data at a much larger scale provide an excellent database for additional more detailed studies by the Geological Survey Branch and other researchers.

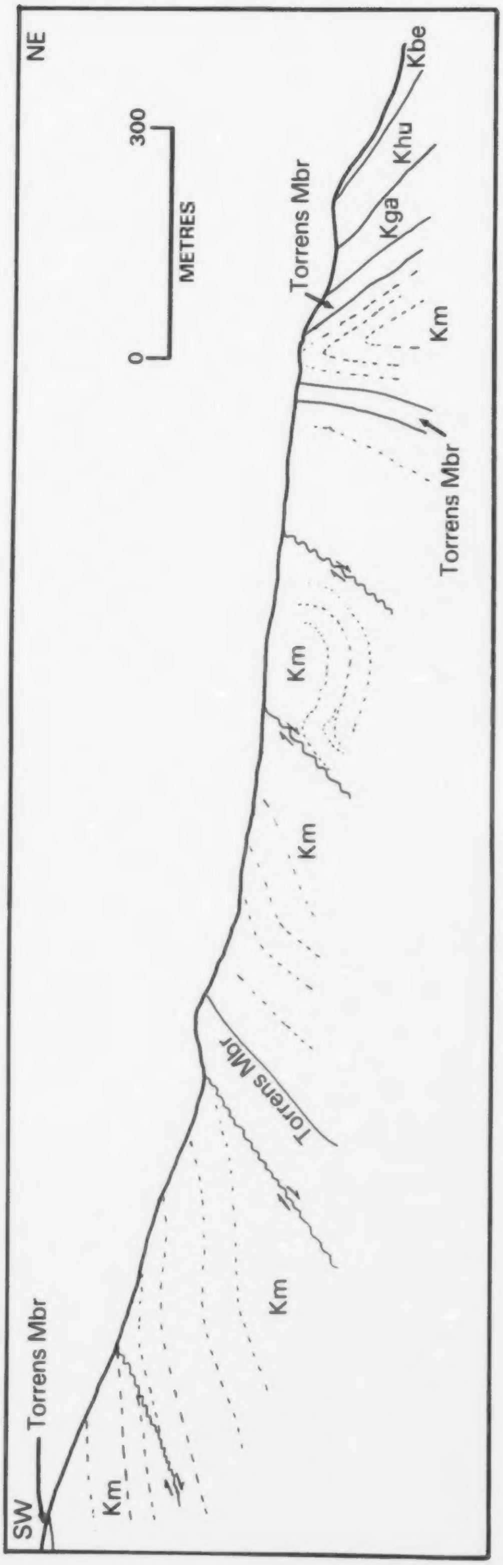

Figure 5-6-6. Line trace drawing from photographs illustrating the deformation style in the Bullmoose fault zone. Location is on east slope of Bullmoose Mountain.

ACKNOWLEDGMENTS

The authors would like to acknowledge the able field and office assistance provided by David Thomas. A significant portion of the software utilized during this project was on loan from Cal Data Ltd.

Funding for this project was shared by the Canada/British Columbia Mineral Development Agreement and the British Columbia Geological Survey Branch. The majority of the outcrop data was collected under the joint federal-provincial Coal Data Acquisition Agreement.

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PALYNOLOGICAL ZONATION AND CORRELATION OF THE PEACE RIVER COALFIELD NORTHEASTERN BRITISH COLUMBIA AN UPDATE*

By Jane Broatch
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The University of British Columbia

As outlined in a previous paper (Broatch, 1986), a good palynozonation has been established for seven sections south of the Burnt River, ranging from the Minnes to Hulcross Formations. Since that time, 52 additional samples of Minnes and Gething have been collected from the Sukunka (26) and Goodrich (26) areas to the north. A total of 264 samples has been processed, of which 220 have been examined microscopically for palynomorphs. The zonation for the Gething through Gates Formations at Bullmoose Mountain in the north has been established and correlated with the sections to the south (Broatch, 1986). Good assemblages have been obtained from the Minnes samples examined, but it is still too early to give a zonation within the northern Minnes, or to correlate to the Jurassic and Lower Cretaceous sections of Minnes to the south. The establishment of this northern zonation is critical because the top of the Minnes is bevelled. Also, the final results should allow for a better estimate of the extent of the hiatus between the upper Minnes and the overlying Cadomin Formation.

The presence of both dinocysts and spore/pollen assemblages has allowed recognition of the facies changes from marine to terrestrial (Figure 5-7-1). Significantly, it has shown a marine unit at the base of the Gething that persists from the northwest to southeast and that splits into an upper and lower tongue in the south, near the Triad Creek area. Two other marine tongues occur in the Gething: one about half way up section that pinches out south of Monkman Pass, and a second that extends just south of Wolverine River. The Gething is separated from the overlying Moosebar Formation by a barren zone interpreted to be largely reworked near-shore terrestrial strata.

The overlying marine Moosebar contains a large assemblage of dinocysts, and thins slightly to the southeast. It is separated from the overlying Gates Formation by a "Transition Unit" (the Torrens Member) that is barren of palynomorphs. The Gates Formation has a thick basal unit that is open-marine at Bullmoose Mountain and that changes rapidly to intertonguing restricted-marine and nonmarine conditions between Bullmoose Mountain and Wolverine River. Above this unit is a middle terrestrial followed by a middle marine interval, both of which are thin. The uppermost section of the Gates contains another terrestrial unit overlain by a marine unit.

In addition to recognizing the main facies, the presence of several restricted species in each formation, and in each member of the Gates (Figure 5-7-2), provides an ideal tool for correlation and dating of separate sections within the coalfield. It is now quite evident that outlying sections both to the north and south will be correlatable with zones in the central area. This is also the case with the Minnes Formation, as shown previously by Broatch (1986), although more work needs to be done to refine the zonation.

REFERENCE

Broatch, J. (1986): Palynological Zonation and Correlation of the Peace River Coalfield, Northeastern British Columbia, *B.C. Ministry of Energy, Mines and Petroleum Resources*, Geological Fieldwork, 1985, Paper 1986-1, pages 321-326.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

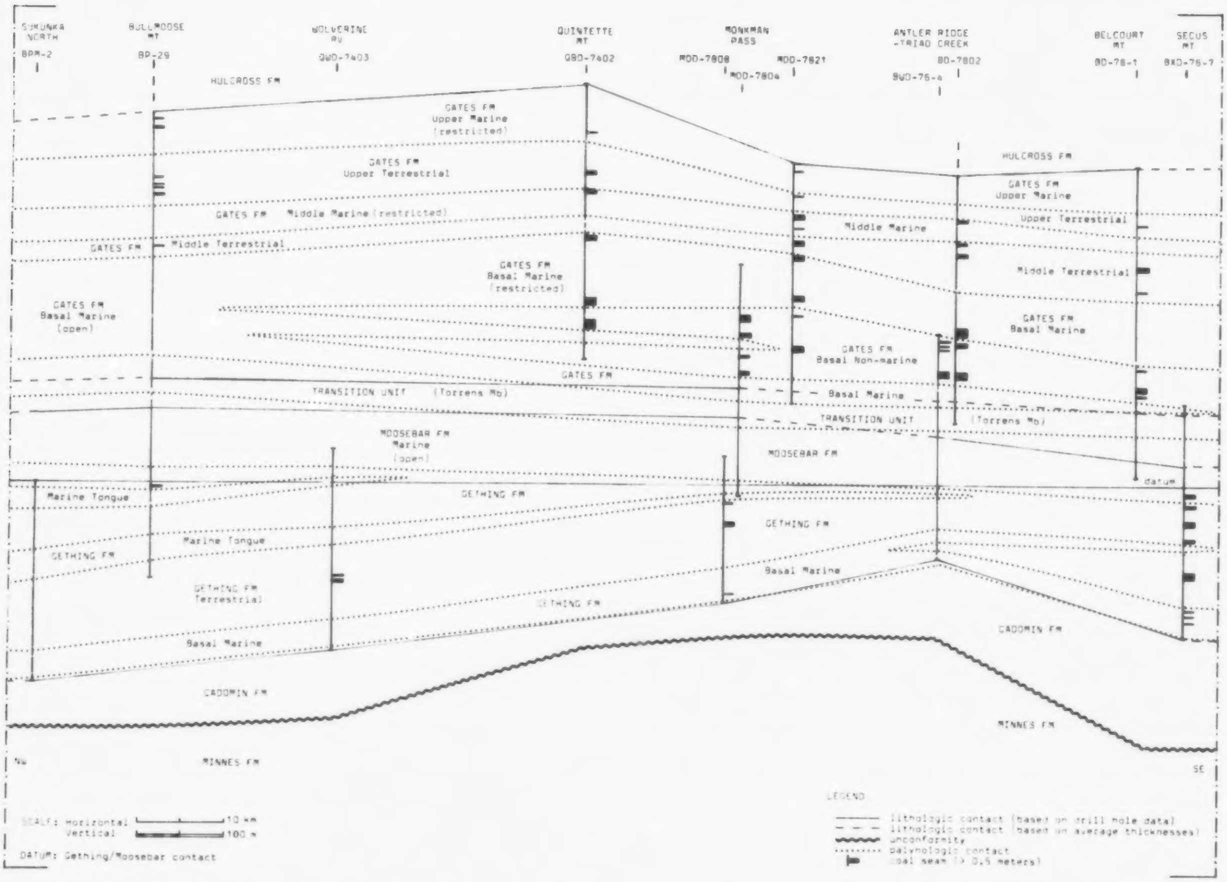
SUKUNKA NORTH
BPM-2
BULLMOOSE MT
BP-29
WOLVERINE RV
QWD-7403
QUINTETTE MT
QBD-7402
MONKMAN PASS
MDD-7808
MDD-7804
MDD-7821
ANTLER RIDGE -TRIAD CREEK
BWD-76-4
BD-7802
BELCOURT MT
BD-76-1
SECUS MT
BXD-76-7
HULCROSS FM
GATES FM Upper Marine (restricted)
GATES FM Upper Terrestrial
GATES FM Middle Marine (restricted)
GATES FM Middle Terrestrial
GATES FM Basal Marine (restricted)
GATES FM Basal Marine (open)
GATES FM
TRANSITION UNIT (Torrens Mb)
MOOSEBAR FM Marine (open)
Marine Tongue
GETHING FM
Marine Tongue
GETHING FM Terrestrial
Basal Marine
GETHING FM
CADOMIN FM
MINNES FM
HULCROSS FM
GATES FM Upper Marine
Upper Terrestrial
Middle Marine
Middle Terrestrial
GATES FM Basal Marine
GATES FM Basal Non-marine
Basal Marine
TRANSITION UNIT (Torrens Mb)
MOOSEBAR FM
datum
GETHING FM
Basal Marine
CADOMIN FM
MINNES FM
NW
SE
SCALE: Horizontal 10 km
Vertical 100 m
DATUM: Gething/Moosebar contact
LEGEND
lithologic contact (based on drill hole data)
lithologic contact (based on average thicknesses)
unconformity
palynologic contact
coal seam (> 0.5 meters)

Figure 5-7-1. Zonation and correlation of the Peace River Coalfield based on total palynomorph assemblage.

EXPLANATION:

Zonation established on the basis of type(s) of palynomorphs present (spores/pollen, dinocysts/acritarchs, algal cysts/fungal spores) and relative abundance and diversity of species. Terrestrial facies are characterized by an absence of marine dinocyst/acritarch species, abundant and/or diverse spore species and moderate numbers of algal and fungal material. Restricted marine facies are characterized by a mixed assemblage of spores, pollen, dinocysts/acritarchs, algal cysts and fungal spores in abundances reflecting proximity to terrestrial or open-marine facies. Open-marine facies are characterized by an abundant and diverse dinocyst/acritarch assemblage.

Much of the terrestrial Gething facies and the entire "Transition Unit" are barren of indigenous palynomorphs suggesting rapid facies changes and reworking of sediments during deposition.

Coal seams greater than 0.5 metre are plotted for reference. Coal depths are based on drill hole logs as are lithologic contacts. Palynologic contacts do not rely on coal seam location but have been placed to emphasize probable concurrent episodes of coal development without compromising palynologic data.

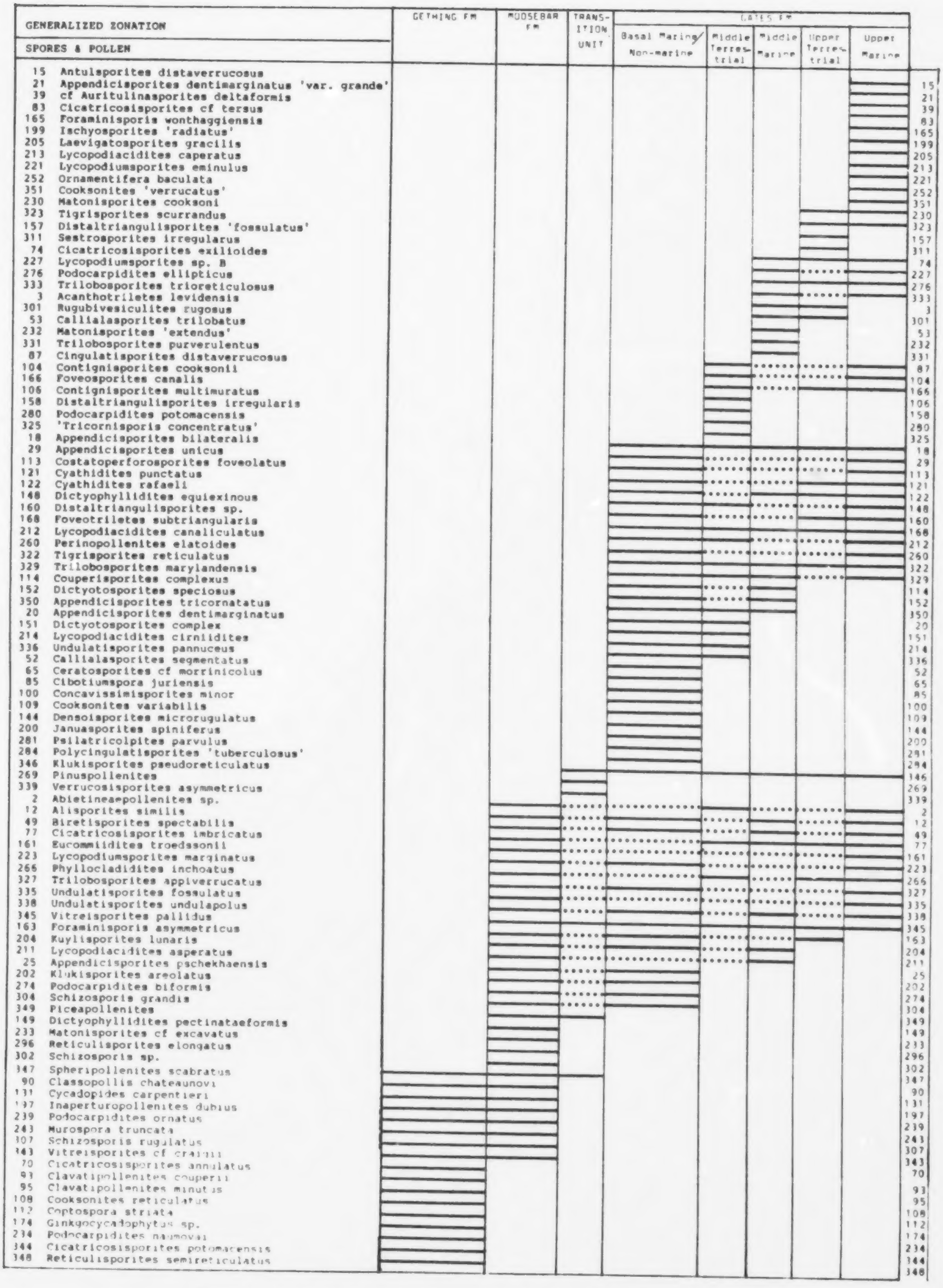

Figure 5-7-2. Generalized species zonation (chart currently under revision).

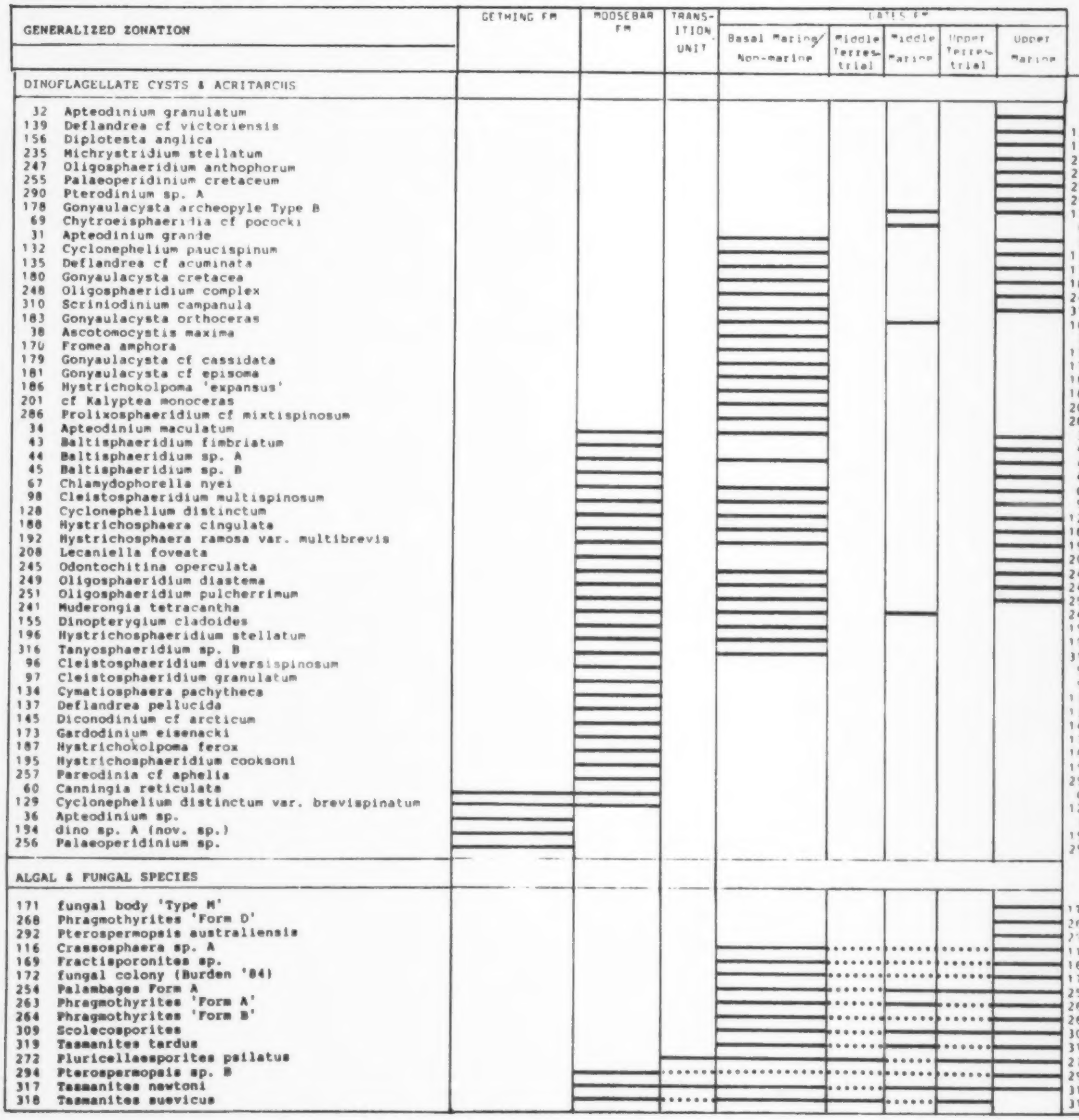

Figure 5-7-2. Generalized species zonation (chart currently under revision) (continued).

Applied Geochemistry

BRITISH COLUMBIA REGIONAL GEOCHEMICAL SURVEY RELEASE — AN ASSESSMENT (93G, 93H and 93J)

By E. L. Faulkner

INTRODUCTION

Data from the joint federal-provincial reconnaissance Regional Geochemical Survey completed in the summer of 1985 were released at 0830 PDT on 9 July 1986 in Prince George, Vancouver and Victoria as the following open files:

Geological Survey of Canada Open File		**British Columbia**
93G	1214	BC RGS 13, 1985
93H	1215	BC RGS 14, 1985
93J	1216	BC RGS 15, 1985

It should be noted that the releases for 93G and 93H include the data released in 1985 for 93G (west half) and 93H (east half) as BC RGS 12, 1984 (Geological Survey of Canada Open File 1107).

Each map sheet covers approximately 14 600 square kilometres with an average sample density of one sample per 13 square kilometres. Stream sediments were analysed for zinc, copper, lead, nickel, cobalt, silver, manganese, arsenic, molybdenum, iron, mercury, uranium, vanadium, cadmium, antimony, barium and loss-on-ignition. Stream waters were analysed for uranium, fluorine and pH. Each open file package consists of a sample location map, 21 geochemical maps and a text of field, analytical and statistical data. Packages are available at a cost of $50 each from: Publications Distribution, 552 Michigan Street, Victoria, British Columbia V8V 1X4.

RESULTS

Fifty-two packages were sold on the day of the release and 23 packages since, for a total of 75 to date, with nearly equal sales of each of the three map sheets. The heavy drift cover in the areas surveyed, particularly 93J, probably contributed to the relatively low interest expressed by industry for this release.

Most of the samples taken from the west half of 93J had losses-on-ignition exceeding 10 per cent, indicating an unacceptably high level of organic matter in these samples. A count of mineral claims in good standing (excluding Crown-granted leases) in the release area for which there was new information — that is, 93G (west half), 93H (east half) and 93J — was made before the field season, the day before the release and after the field season.

The results are as follows:

Date of Count	**27 May 1986**	**8 July 1986**	**20 Oct. 1986**	
93G (west half)	109	114	152	Claim Units
	5	5	5	2 Post Claims
93H (east half)	90	121	261	Claim Units
	14	12	39	2 Post Claims
93J	874	1116	1109	Claim Units
	44	94	60	2 Post Claims

The totals for 93J are complicated by the facts that a large block of claims, staked some years ago, lapsed after the release date, and some new staking was subsequently disallowed. There was also some preemptive staking in 93J by two companies before the release. Taking these facts into consideration, there was a modest amount of new staking in all three areas that can be attributed to the results of the survey.

Two areas, 93H/9 and 93J/8, attracted the most interest. Both are areas of Hadrynian to Lower Paleozoic sedimentary rocks with anomalies possibly related to shale or carbonate-hosted base metal and silver mineralization (Figure 6-1-1).

FOLLOW-UP OF 1985 RGS RELEASE

The results of the 1985 RGS release continue to have a significant impact on exploration activity, as can be seen from the staking totals for 93G (east half) and 93H (west half) which follow:

Date of Count	**Pre-1985 Release**	**Post-1985 Field Season**	**20 Oct. 1986**	
93G (east half)	3042	3603	4277	Claim Units
	103	178	182	2 Post Claims
93H (west half)	2811	3321	3212	Claim Units
	243	254	265	2 Post Claims
Total	5853	6924	7489	Claim Units
	346	432	447	2 Post Claims

An examination of the areas staked in relation to the survey results, together with information from project geologists, conservatively indicates that at least half of the new staking is a consequence of the survey results. Areas that have received the most attention are shown on the outline geological map, Figure 6-1-1. Generally they have either multi-element anomalies, possibly related to volcanogenic massive sulphide mineralization in the Quesnel trough, or base metal and barium anomalies possibly related to sediment-hosted base metal and silver mineralization.

COMMENTS

Both releases have generated significant exploration activity. Although details of exploration expenditures in the release area are not known, monitoring of exploration programs suggests that 1985 and 1986 expenditures of close to $1 million can be at least partly attributed to the survey results. This compares favourably with the total cost of the two releases — approximately $430 000.

REFERENCE

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British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

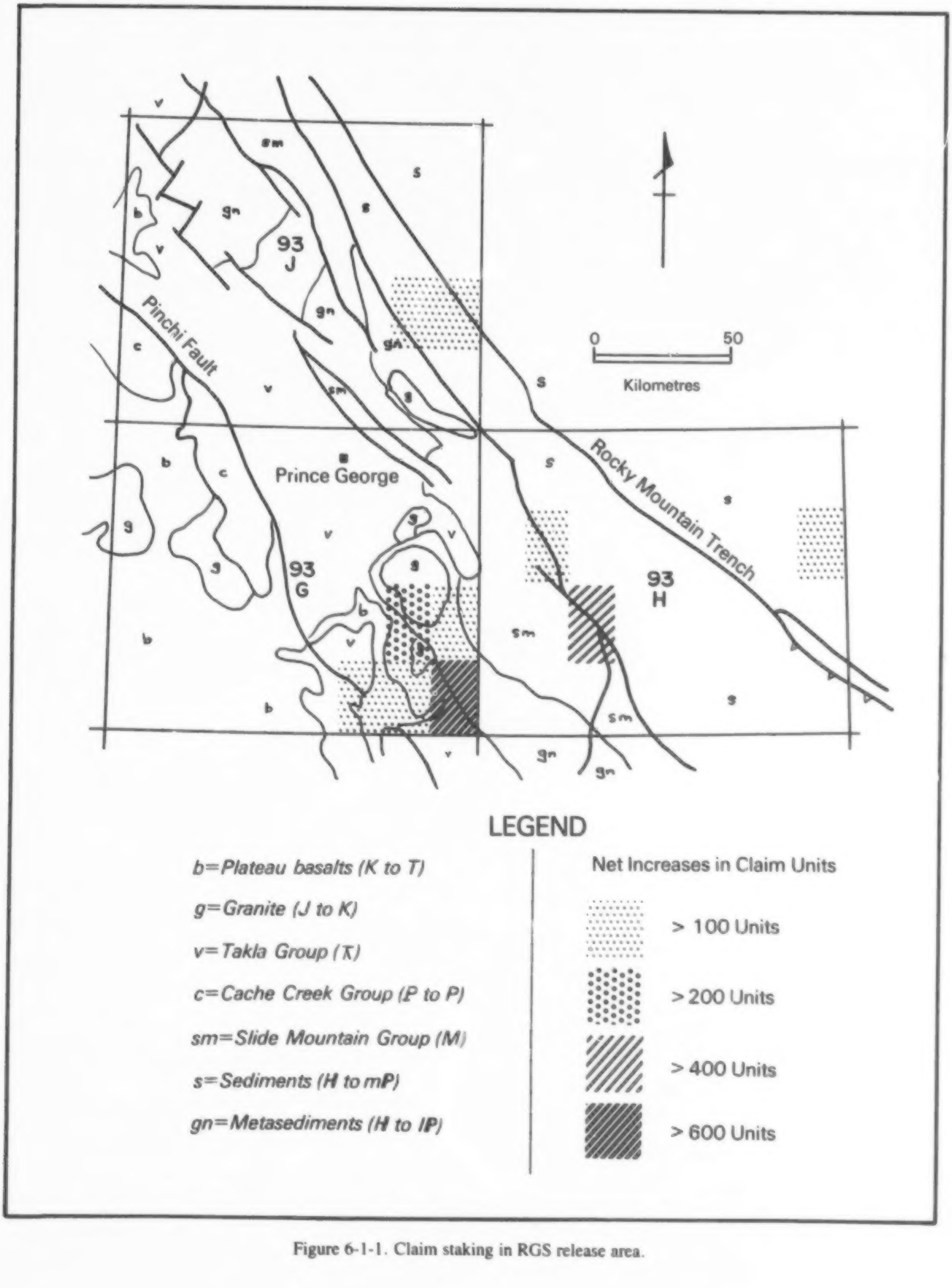
93 J
93 G
93 H
Pinchi Fault
Rocky Mountain Trench
Prince George
0
50
Kilometres
LEGEND
b=Plateau basalts (K to T)
g=Granite (J to K)
v=Takla Group (TR)
c=Cache Creek Group (P to P)
sm=Slide Mountain Group (M)
s=Sediments (H to mP)
gn=Metasediments (H to lP)
Net Increases in Claim Units
> 100 Units
> 200 Units
> 400 Units
> 600 Units

Figure 6-1-1. Claim staking in RGS release area.

A NEW LOOK FOR REGIONAL GEOCHEMICAL SURVEY DATA*

By P. F. Matysek

INTRODUCTION

Reconnaissance stream sediment sampling data published during the last 10 years has helped delineate regional geochemical patterns throughout much of the province, and provided a comprehensive data set that can be used as baseline information for more detailed studies. The database represents an investment of more than $3 million but because it has only been available on magnetic tape, only a few researchers and explorationists have had the facilities to realize its full potential. To make the data more readily accessible to a wider segment of the exploration industry, it has now been made available on floppy diskettes.

THE REGIONAL GEOCHEMICAL SURVEY DATABASE: A SUMMARY

The Geological Survey Branch of the British Columbia Ministry of Energy, Mines and Petroleum Resources has been involved in regional geochemical sediment surveys since 1976. The database represents multi-element determinations and field observations of reconnaissance stream sediment and water sampling of twenty-two 1:250 000 National Topographic System (NTS) map sheet areas. Figure 6-2-1 illustrates the areal distribution of these surveys.

The objectives of the British Columbia Regional Geochemical Survey (RGS) and its predecessor, the joint Federal/Provincial Uranium Reconnaissance Program (URP) are threefold, and are summarized as follows:

(1) To provide industry with high-quality reconnaissance exploration data to aid in the search for uranium and up to 19 other metals, particularly precious and base metals;

(2) To provide a consistent national database for these metals to serve as a basis for resource appraisal;

(3) To provide a comprehensive data set that will delineate the regional geochemical patterns throughout the province and be used as baseline information for more detailed studies.

Program design, based on preliminary orientation studies,[1] requires collection of sediments with an average density of one sample per 13 square kilometres from secondary or tertiary drainages. One kilogram of active stream sediment and 0.25 litre of water are collected at each site. Field observations on characteristics of the drainage catchment, sample site and sediment sample are also recorded. Samples are field-dried and the -80 mesh (<177 microns) fraction is routinely analysed for zinc, copper, lead, nickel, cobalt, silver, manganese, iron, molybdenum, tungsten, and uranium. Water samples are analysed for uranium, fluorine and pH. In response to industry demand, additional elements have been added to the surveys and include mercury, tin, arsenic, antimony, barium, cadmium, vanadium and loss-on-ignition.

Sample collection, sample preparation and water and sediment analyses are carried out by separate contractors. Personnel from the Geological Survey Branch have been responsible for supervision, management and quality control of the program since 1978. Data entry, digitizing, plotting, listings, and compilation for statistics have been done by the Geological Survey of Canada.

Results are usually released in May or June of the year following sample collection. A considerable effort is made to ensure that the data is secure until released. The data packet typically includes a sample location map, detailed listings, statistical summaries, and in some instances, maps for individual elements showing range symbols or values. The packet is available for purchase at a nominal price from the Publication Distribution centre at the British Columbia Ministry of Energy, Mines and Petroleum Resources in Victoria, or from Campbell's Reproduction in Ottawa. Results from the RGS can also be accessed for reference at all libraries of the Geological Survey of Canada, the Map Library at The University of British Columbia, and the Ministry Library in Victoria.

A great many new mineral prospects have been discovered, old ones have been re-evaluated, and a number of areas previously thought to have little mineral potential have been investigated as a result of the regional geochemical surveys. Information extracted from the RGS database has been useful not only for exploration work[2], but also for identifying the reliability of the data[3], for use in regional metallogenic studies[4], and as a database for land use decisions[5], environmental studies[6], and geological interpretations and projections[7].

THE PROBLEM: ACCESSIBILITY

The nature of such large multi-element surveys leads to the accumulation of enormous amounts of data; the RGS database contains information on both field and analytical data for more than 23 000 samples (Table 6-2-1). The means to store and access the data effectively must be examined carefully, if for no other reason than the high cost of its acquisition. More important, from the point of view of the exploration community, are the limitations inherent in a simple visual and manual interpretation of such complex and voluminous data. Subtle but significant information is likely to remain undetected. Processing by mathematical and statistical procedures can provide a more detailed interpretation and because of the volume of data involved, use of computers is essential. In response to this demand, RGS data were made available in digital form on high density magnetic tape in a format compatible with a wide range of mainframe installations.

Numerous processing and interpretative techniques have been developed to evaluate the RGS database[8]. In each case, computer manipulation and processing were essential for the efficient extraction of useful information. Unfortunately only a relatively small part of the mining community has the appropriate computer facilities (mini or mainframe installations with tape drives) to access and make use of this extensive and valuable database. Furthermore, the

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[1] Ballantyne and Bottriel, 1975, Ballantyne, 1976, Ballantyne *et al.*, 1978, and Boyle and Ballantyne, 1980.

[2] Church, 1980, Panteleyev, 1980, Christopher, 1980, Boronowski, 1985.

[3] Matysek, 1985

[4] Sutherland Brown, 1980, Johnson, 1984, National Geochemical Reconniassance 1:2 000 000 coloured compilation map series (1981).

[5] McLaren, 1985

[6] Sutherland Brown *et al.*, 1979.

[7] Panteleyev, 1980, Matysek *et al.*, 1984.

[8] Sinclair and Fletcher, 1980, Matysek *et al.*, 1981, 1982, Addie, 1982, and Johnson, 1984.

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

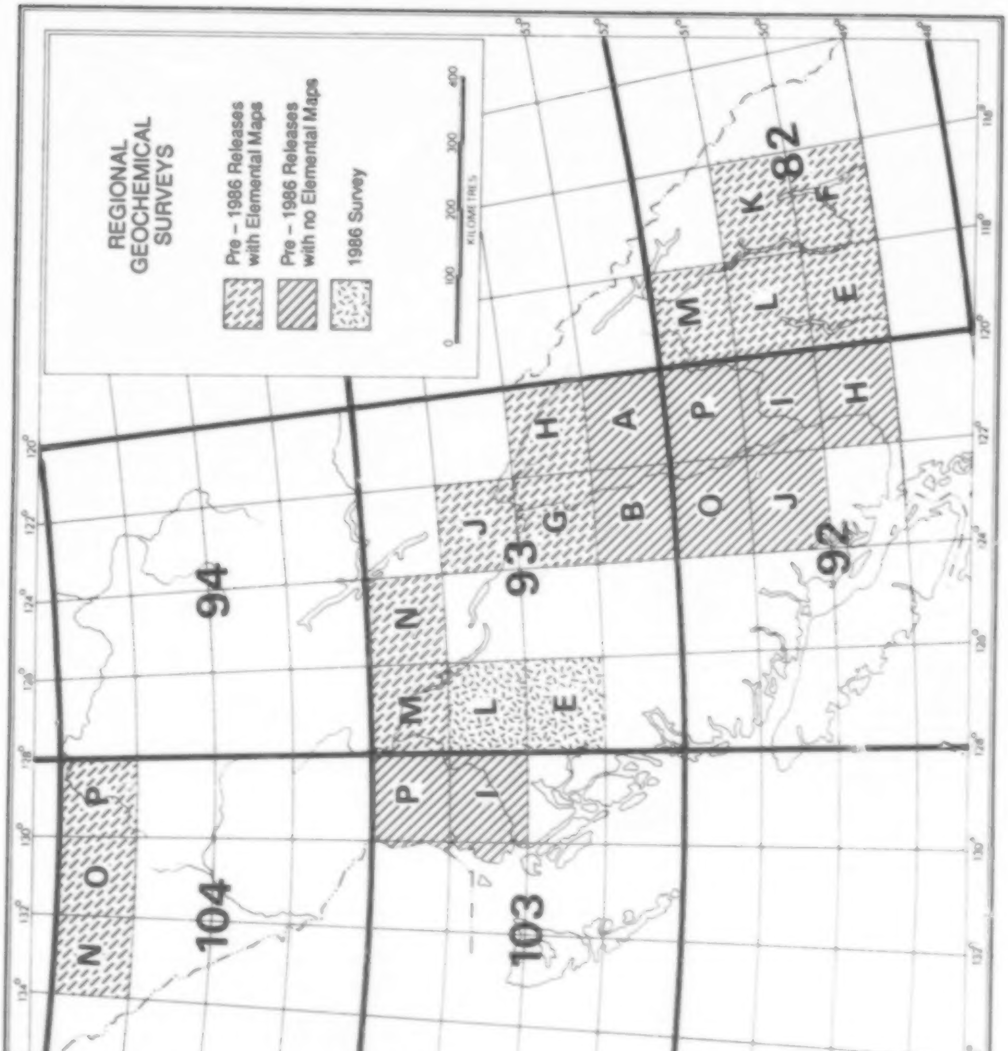
REGIONAL GEOCHEMICAL SURVEYS
Pre – 1986 Releases with Elemental Maps
Pre – 1986 Releases with no Elemental Maps
1986 Survey
0
100
200
300
400
KILOMETRES
94
104
103
93
92
82
N
O
P
P
I
M
L
E
N
J
G
H
B
A
O
P
J
I
H
M
L
K
F
E
60°
59°
58°
57°
56°
55°
54°
53°
52°
51°
50°
49°
48°
138°
136°
134°
132°
130°
128°
126°
124°
122°
120°
118°
116°

Figure 6-2-1. Areal Distribution of Regional Geochemical Survey Program.

TABLE 6-2-1
SUMMARY STATISTICS OF COMPUTER ACCESSIBLE RGS DATABASE
CANADA — BRITISH COLUMBIA
REGIONAL STREAM SEDIMENT AND WATER SAMPLING PROGRAM

NTS MAPSHEET	BRITISH COLUMBIA RELEASE AND GEOLOGICAL SURVEY OF CANADA OPEN FILE		COLLECTION YEAR	AREA SQ KM	SAMPLE SITES	DENSITY SITES/10 SQ KM	DENSITY SITE/SQ KM	ROUTINE ELEMENT SUITE	ADDITIONAL ELEMENTS							
									Sn	Hg	As	Sb	Ba	Cd	V	LOI
82E	NGR 05	OF 409	1976	16 000	1631	1.0	9.8	●								
82L	NGR 06	OF 410	1976	15 700	1385	0.9	11.3	●								
82F	NGR 25	OF 514	1977	16 000	1394	0.9	11.4	●	●	●						
82K	NGR 26	OF 515	1977	15 700	1297	0.8	12.1	●	●	●						
82M	NGR 27	OF 516	1977	15 400	1219	0.8	12.6	●	●	●						
104N	NGR 28	OF 517	1977	12 500	936	0.7	13.3	●	●	●						
104O	NGR 41	OF 561	1978	12 500	946	0.8	13.2	●		●	●					
104P	NGR 42	OF 562	1978	12 500	848	0.7	14.7	●		●	●					
103I	BC RGS 01	OF 772	1978	14 300	1908	1.3	7.5	●		●	●					
103J	BC RGS 01	OF 772	1978	1 500	326	2.1	4.6	●		●	●					
103P	BC RGS 02	OF 773	1978	14 000	1796	1.3	7.8	●		●	●					
103O	BC RGS 02	OF 773	1978	800	87	1.1	9.2	●		●	●					
92O	BC RGS 03	OF 774	1979	15 400	935	0.6	16.5	●		●	●					
92P	BC RGS 04	OF 775	1979	15 700	914	0.6	17.2	●		●	●					
93A	BC RGS 05	OF 776	1980	15 000	1299	0.9	11.5	●		●	●	●				
93B	BC RGS 06	OF 777	1980	15 000	757	0.5	19.8	●		●	●	●				
92H	BC RGS 07	OF 865	1981	16 000	995	0.6	16.1	●		●	●	●				
92I	BC RGS 08	OF 866	1981	15 700	606	0.4	25.9	●		●	●	●				
92J	BC RGS 09	OF 867	1981	15 700	853	0.5	18.4	●		●	●	●				
93M	BC RGS 10	OF 1000	1983	14 000	1100	0.8	12.7	●		●	●	●				
93N	BC RGS 11	OF 1001	1983	14 000	1124	0.8	12.4	●		●	●	●				
93G (E/2)	BC RGS 12	OF 1107	1984	7 300	585	0.8	12.5	●		●	●	●	●	●	●	●
93H (W/2)	BC RGS 12	OF 1107	1984	7 300	650	0.9	11.2	●		●	●	●	●	●	●	●
TOTAL				298 000	23 591	0.8	12.6									

Note: Routine Element Suite consists of analyses of stream sediment for Zn, Cu, Pb, Ni, Co, Ag, Mn, Fe, Mo, U, W and of analyses of stream waters for U, F and pH. Open Files 517 and 561 also contain lake sediment data.

database which is currently available on magnetic tape requires considerable inputting and editing to ensure complete, consistent and systematic organization of the data.

THE SOLUTION: RGS DATABASE ON FLOPPY DISKETTES

The advent of inexpensive microcomputers has provided the majority of mineral exploration companies with the power to apply sophisticated data management and analysis techniques to geochemical and geological field data. To make the RGS data accessible to this new group of users, the entire database has been downloaded onto floppy diskettes. The increased accessiblity will promote a more thorough and refined assessment, and bring about a closer realization of the data's full potential.

THE PRODUCT: DETAILS

The RGS database has been split into separate datafiles, corresponding to 1:250 000 NTS map sheets, and stored on standard MS-DOS, double-sided, double-density, 5 1/4-inch floppy diskettes. Two text files are also included: a "Preamble" file describing the logistical details of the survey, and a "Format" file describing the nature and organization of the data. All files are stored in standard ASCII format.

In most cases, a single floppy diskette provides sufficient space (360 kilobytes) for data for one map-sheet and related text files. The total size of the RGS database, as it resides on floppy diskettes, is approximately 6 megabytes.

RGS DATAFILE

For greater manageability, individual map sheets have been split into an east and west half and are stored as two separate sequential files. Information pertaining to each sample is stored on three fixed-length 80-character records. Record one contains the field data; records two and three contain the analytical data.

All records for each sample have certain features in common: the first 12 columns always contain the NTS map sheet and sample number, and the last column of the record, column 80, contains an "X", which denotes the end of the record.

Sequential files are the simplest form to handle, being fully provided for in nearly all programming implementations, and requiring no special processing techniques. Fixed length data records are simple to manipulate and are readily transferred between computers.

PREAMBLE TEXT FILE

The "Preamble" file describes all relevant historical and technical details of the project. It identifies the supervisory personnel responsible for technical aspects of the survey and the contractors selected for sample collection, preparation, chemical analyses, and data preparation. It also describes the field, analytical and data preparation methods used, and lists relevant geological references.

TABLE 6-2-2.
RECORD FORMAT FOR INDIVIDUAL SAMPLES

Record 1: Field Information

Field	Description	Record	Columns	Length	Example
01	Map Sheet	1	01-06	6	104N16
02	ID (Year, Crew, Number)	1	07-12	6	841102
03	UTM Zone	1	14-15	2	10
04	UTM Easting (Metres)	1	16-21	6	544654
05	UTM Northing (Metres)	1	22-28	7	5911939
06	Rock Type	1	30-33	4	GRNT
07	Stratigraphic Age	1	34-35	2	36
08	Stream Width (Decimetres)	1	37-39	3	35
09	Stream Depth (Decimetres)	1	40-42	3	3
10	Elevation (Metres)	1	43-46	4	750
11	Sample Material	1	47	1	6
12	Replicate Status	1	48-49	2	00
13	Contamination	1	51	1	1
14	Bank Type	1	52	1	3
15	Water Colour	1	53	1	2
16	Water Flow Rate	1	54	1	2
17	Sediment Colour	1	55	1	6
18	Sediment Composition	1	56-58	3	013
19	Stream Precipitate	1	60	1	2
20	Local Precipitate	1	61	1	3
21	Physiography	1	62	1	2
22	Drainage Pattern	1	63	1	2
23	Stream Type	1	64	1	1
24	Stream Class	1	65	1	3
25	Stream Source	1	66	1	4
26	Date Collected (Day, Month)	1	68-71	4	1908

Record 2: (Map Sheet) ID and Analytical Data

Field	Description	Record	Columns	Length	Example
01	Map Sheet	2	01-06	6	104N16
02	ID (Year, Crew, Number)	2	07-12	6	841102
03	Zinc (PPM)	2	16-20	5	70
04	Copper (PPM)	2	21-25	5	39
05	Lead (PPM)	2	26-30	5	2
06	Nickel (PPM)	2	31-35	5	50
07	Cobalt (PPM)	2	36-40	5	19
08	Silver (PPM)	2	41-45	5	0.1
09	Manganese (PPM)	2	46-50	5	680
10	Iron (PCT)	2	51-55	5	3.00
11	Molybdenum (PPM)	2	56-60	5	2
12	Tungsten (PPM)	2	61-65	5	10
13	Tin (PPM)	2	66-70	5	4
14	Barium (PPM)	2	71-75	5	250
15	Loi (PCT)	2	76-79	4	23.2

Record 3: (Map Sheet) ID and Remainder of the Analytical Data

Field	Description	Record	Columns	Length	Example
01	Map Sheet	3	01-06	6	104N16
02	ID (Year, Crew, Number)	3	07-12	6	841102
03	Arsenic (PPM)	3	16-20	5	3.0
04	Antimony (PPM)	3	21-25	5	4.2
05	Mercury (PPB)	3	26-30	5	10
06	Optional Element 1	3	31-35	5	
07	Optional Element 2	3	36-40	5	
08	Optional Element 3	3	41-45	5	
09	Optional Element 4	3	46-49	4	
10	Cadmium (PPM)	3	50-54	5	2.5
11	Vanadium (PPM)	3	55-59	5	125
12	Uranium (PPM)	3	60-64	5	2.0
13	Uranium in Water (PPB)	3	65-69	5	0.46
14	Fluorine in Water (PPB)	3	70-74	5	62
15	pH of Stream Water	3	75-79	5	8.3

FORMAT TEXT FILE

The "Format" file describes the nature and organization of the data. The format for each record is described in Table 6-2-2. Table 6-2-3 lists the field observation codes for characteristics of the drainage catchment, sample site and sediment sample.

THE EXTRAS

A number of enhancements are available to further increase the flexibility and accessiblity of the data. A public domain database management system, designed specifically for the RGS database, is available at a nominal cost. The system is written in BASIC, and provides selective retrieval and display capabilities.

The format of the data file was originally designed to produce an easily readable listing. However, some users' applications may require that all information for each sample is stored on the same record. A small application program is available which reformats the data into a fixed record length file with one sample per record. The program is available in both BASIC and FORTRAN.

Tables 6-2-4 and 6-2-5 list major rock types and stratigraphic ages of sampled catchment areas. These compilations are useful in assisting in the selection of map sheets on a geological basis.

THE COSTS

Floppy diskettes are available from the Publications Distribution Section of the Ministry. The cost to acquire individual 1:250 000 RGS datafiles is $12. Interested parties should direct their requests and queries in writing to:

Paul Matysek
Project Geochemist
Geological Survey Branch
Parliament Buildings
Victoria, British Columbia
V8V 1X4

THE BENEFITS

(1) RGS database is stored in a complete and consistent format.

(2) It can be accessed by a significantly larger group of explorationists and research scientists.

(3) RGS data can now be evaluated by available microcomputer software to suit the user's specific needs.

(4) Detailed analysis of the database will lead to renewed interest in previously sampled areas.

(5) Future updates (new analyses and interpretations) can be inexpensively distributed to the public.

TABLE 6-2-3
EXPLANATION OF CODES FOR FIELD OBSERVATIONS LISTED IN RECORD 1

Field	Columns	Description
1	01 – 06	MAP SHEET: National Topographic System (NTS) Lettered Quadrangle (1:50 000 or 1:250 000 Scale)
2	07 – 12	ID / SAMPLE NUMBER: Consists of three parts, last two digits of the Collection Year (COL 7- 8) then Field Party Number (COL 9) then a sequential Number (COL 10-12)
	14 – 28	SAMPLE SITE LOCATION: Utilizes the Universal Transverse Mercator (UTM) System and consists of three parts,
3		A UTM Zone (COL 14-15)
4		then UTM Eastings (COL 16-21)
5		then UTM Northings (COL 22-28)
6	30 – 33	ROCK TYPE: Major rock type of catchment area Four character mnemonic employed For example: BSLT = Basalt SCST = Schist CHRT = Chert TILL = Till
7	34 – 35	AGE: Stratigraphic age of major rock type Two digit system employed For example: 16 = Silurian 36 = Cretaceous 24 = Permian 42 = Tertiary
8	37 – 39	STREAM WIDTH: Width of the stream at the sample site to the nearest decimetre
9	40 – 42	STREAM DEPTH: Depth of the stream at the sample site to the nearest decimetre
10	43 – 46	ELEVATION: Elevation at the sample site to the nearest metre
11	47	SAMPLE MATERIAL: Nature of media sampled 1 — Stream Sediment 4 — Stream Water 2 — Spring Sediment 5 — Spring/Well Water 3 — Heavy Mineral Concentrate 6 — Simultaneous Stream Water and Sediment
12	48 – 49	REPLICATE STATUS: Relationship of the current sample to others in the Project 00 — Routine sample site 10 — First of a field duplicate pair 20 — Second of a field duplicate pair
13	51	CONTAMINATION: Degree or type of Human Contamination 0 — None 4 — Mining activity 1 — Possible 6 — Agricultural 2 — Probable 7 — Domestic sources 3 — Definite 8 — Forestry activity
14	52	BANK-TYPE: General Nature of the Bank Material 0 — Undefined 4 — Glacial outwash 1 — Alluvial 5 — Bare rock 2 — Colluvial 6 — Talus, Scree 3 — Glacial Till 7 — Organic
15	53	WATER COLOUR: General Colour and Suspended Load of the Water 0 — Clear 2 — White cloudy 1 — Brown transparent 3 — Brown cloudy
16	54	WATER FLOW RATE: 0 — Stagnant 3 — Fast 1 — Slow 4 — Torrent 2 — Moderate
17	55	SEDIMENT COLOUR: 1 — Red, Brown 5 — Green 2 — White, Buff 6 — Grey 3 — Black 7 — Pink 4 — Yellow
18	56 – 58	SEDIMENT COMPOSITION: Bulk composition of the collected sample as a function of abundance of sand, fines and organics 0 — Absent 2 — Medium 33-67% 1 — Minor < 33% 3 — Major > 67% Sand > 0.125 mm (COL 56) Fines, Silt and Clay < 0.125 mm (COL 57) Organics (COL 58)
19	60	SEDIMENT PRECIPITATE OR STAIN: Presence of any coatings on pebbles, boulders or stream bottoms near the sample site 0 — None 4 — Yellow 1 — Red, Brown 5 — Green 2 — White, Buff 6 — Grey 3 — Black
20	61	LOCAL PRECIPITATE: Presence of stain, weathering; bloom on rocks in immediate catchment area 0 — Featureless 4 — Yellow 1 — Red, Brown 5 — Green 2 — White, Buff 6 — Grey 3 — Black
21	62	PHYSIOGRAPHY: 0 — Plain 3 — Hilly, undulating 1 — Muskeg, Swampland 4 — Mountainous, mature 2 — Peneplain, Plateau 5 — Moutainnous, youthful
22	63	DRAINAGE PATTERN: 0 — Poorly Defined 4 — Braided 1 — Dendritic 5 — Discontinuous 2 — Herringbone 6 — Basinal 3 — Rectangular 7 — Other
23	64	STREAM TYPE: 0 — Undefined 2 — Intermittent, seasonal 1 — Permanent 3 — Re-emergent, discontinuous
24	65	STREAM CLASS: 0 — Undefined 3 — Tertiary 1 — Primary 4 — Quaternary 2 — Secondary
25	66	STREAM SOURCE: 0 — Unknown 3 — Recent precipitation 1 — Groundwater 4 — Glacier melt water 2 — Spring run-off
26	68 – 71	SAMPLE COLLECTION DATE: Day (2 Digit) and Month (2 Digit)

Table 6-2-4. MAP-SHEET DISTRIBUTION OF MAJOR ROCK-TYPES IDENTIFIED OR INFERRED FOR SAMPLED CATCHMENT AREAS

1:250 000 MAP-SHEET LOCATION

FIELD CODE	DESCRIPTION	82E	82F	82K	82L	82M	92H	92I	92J	92O	92P	93A	93B	93G	93H	93M	93N	103I	103J	103O	103P	104N	104O	104P
AGCL	— Argillaceous Limestone																							●
AGLM	— Agglomerate											●												
ALSK	— Alaskite																					●		
ANDS	— Andesite	●	●	●			●	●	●	●	●			●		●	●					●		
ARGL	— Argillite		●	●				●	●						●									
BSLT	— Basalt						●			●	●	●	●	●	●	●	●				●	●		
CGLM	— Conglomerate	●	●	●			●	●					●	●	●	●	●							●
CHRT	— Chert											●		●								●	●	
DCIT	— Dacite							●		●	●													
DLMT	— Dolomite		●	●											●								●	●
FPCA	— Feldspathic Sandstone														●									
GBBR	— Gabbro															●								
GNSS	— Gneiss	●	●	●	●	●												●	●				●	
GRCK	— Graywacke								●													●	●	
GRDR	— Granodiorite Gneiss			●								●	●	●										
GRNG	— Granitoid Gneiss																●							
GRNS	— Greenstone	●			●		●	●	●		●						●						●	●
GRNT	— Granite	●	●		●	●	●	●	●	●	●						●	●	●	●	●	●	●	
IEXV	— Intermediate Extrusive						●																	
LMSN	— Limestone		●	●				●		●	●	●	●			●	●					●	●	●
LMDM	— Limestone, Dolomite																●							
MSDM	— Metasediment								●									●	●					
MVCC	— Metavolcanic																	●		●	●	●		
OLVB	— Olivine Basalt	●			●	●																●		
PCLC	— Pyroclastic																					●		
PLLT	— Phyllite											●		●	●		●						●	
PRDT	— Peridotite						●																	
QRTZ	— Quartzite		●	●	●	●						●			●									●
QRZD	— Quartz Diorite																						●	
QTMZ	— Quartz Monzonite			●										●		●							●	
RDCT	— Rhyodacite								●															
RYLT	— Rhyolite												●	●		●	●							
SCST	— Schist		●	●	●	●		●																
SHLE	— Shale		●						●					●	●	●	●							
SLSN	— Siltstone									●	●							●			●			
SLTE	— Slate		●	●			●																	
SMRK	— Sedimentary Rock																					●		
SRPN	— Serpentinite							●	●								●						●	●
SNDS	— Sandstone						●							●										
SYNT	— Syenite	●	●		●																			
TILL	— Till	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●	●	●
TUFF	— Tuff															●							●	
UMFC	— Ultramafic	●				●																●		
		82E	82F	82K	82L	82M	92H	92I	92J	92O	92P	93A	93B	93G	93H	93M	93N	103I	103J	103O	103P	104N	104O	104P

Table 6-2-5. MAP-SHEET DISTRIBUTION OF THE STRATIGRAPHIC AGE OF SAMPLED CATHMENT AREAS

1:250 000 MAP-SHEET LOCATION

FIELD CODE DESCRIPTION	82E	82F	82K	82L	82M	92H	92I	92J	92O	92P	93A	93B	93G	93H	93M	93N	103I	103J	103O	103P	104N	104O	104P
04 — Proterozoic			●								●					●							
06 — Helikian		●	●																				
07 — Hadrynian		●	●										●	●									●
10 — Paleozoic undivided		●	●			●	●	●								●	●	●					
11 — Proterozoic-Paleozoic										●												●	●
12 — Cambrian		●	●								●			●									●
13 — Cambrian-Ordivician			●																				●
14 — Ordovician																							
15 — Ordovician-Silurian			●																				
16 — Silurian														●									
17 — Silurian-Devonian																●							
18 — Devonian														●								●	●
19 — Devonian-Mississippian																						●	●
20 — Carboniferous																						●	●
21 — Mississippian													●	●									
22 — Pennsylvanian										●													
23 — Pennsylvanian-Permian													●		●	●							
24 — Permian							●		●	●	●	●											
30 — Mesozoic undivided		●					●		●		●												
31 — Paleozoic-Mesozoic						●	●																
32 — Triassic		●	●			●	●	●	●	●			●	●	●	●							
33 — Triassic-Jurassic		●										●	●				●	●	●	●		●	
34 — Jurassic		●				●				●			●		●	●						●	
35 — Jurassic-Cretaceous		●	●			●		●							●		●	●	●	●		●	
36 — Cretaceous						●	●	●	●				●		●	●						●	●
40 — Cenzoic undivided																							
41 — Mesozoic-Cenzoic						●	●	●	●	●	●	●	●		●	●	●	●	●	●			●
42 — Tertiary		●				●	●	●	●	●	●	●	●		●							●	●
43 — Tertiary-Quaternary								●			●	●										●	
44 — Quaternary						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●
50 — Unknown																●							
	82E	82F	82K	82L	82M	92H	92I	92J	92O	92P	93A	93B	93G	93H	93M	93N	103I	103J	103O	103P	104N	104O	104P

NOTE: Stratigraphic ages of sampled catchment areas not determined for map-sheets 82E, 82L, 82M and 104N.

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COMPARATIVE STUDY OF RECONNAISSANCE STREAM SEDIMENT SAMPLING TECHNIQUES FOR GOLD: FIELDWORK*

(93L)

By P. F. Matysek and D. W. Saxby

A study has been implemented to directly compare the effectiveness of a variety of stream sediment sampling techniques for regional gold exploration. This report describes the objectives, completed fieldwork and proposed sample processing.

INTRODUCTION

Reconnaissance drainage surveys for gold deposits have historically employed two procedures, conventional stream sediment and heavy mineral sampling. However, gold concentrations indicated by such surveys, and their innumerable variations, have typically been erratic, nonreproducible in the field and difficult to interpret. Both sampling approaches have produced false anomalies and ensuing wasteful follow-up programs, but even more importantly, have in some cases failed to identify true anomalies.

There is substantial evidence from previous researchers that these problems of poor reliability principally arise from (1) low numbers of gold grains in stream sediments, causing high random sampling errors (Clifton *et al.*, 1969; Harris, 1982; Day and Fletcher, 1985), and (2) localized and variable distribution of high density gold grains as a result of selective hydraulic sorting (Wells, 1973 and Saxby and Fletcher, 1986).

Further insight on the general nature of these problems is gained from recent stream sediment studies on the within-site variability of two other heavy minerals, cassiterite (Fletcher *et al.*, 1985) and scheelite (Saxby, 1984). Both studies found that errors caused by particle scarcity and selective sorting of heavy minerals decrease with decreasing grain size and that sampling for finer grain sizes (-270 mesh, <60 microns) is therefore advisable.

Based on the above considerations, this study compares the reliability of conventional stream sediment and heavy mineral sampling for various sizes of gold particles. This is accomplished by using replicate samples from known anomalous and background drainages to estimate within-site variability, and hence the probability of obtaining a geochemical value indicative of a (1) true anomaly, (2) false (nonsignificant) anomaly, (3) false background (missed anomaly), and (4) true background.

FIELDWORK: SAMPLE COLLECTION

Eighty bulk sediment samples were collected by the authors from nine streams draining Hazelton Group lithologies in northwestern British Columbia, NTS 93L (Figure 6-3-1). For the most part, sampling was restricted to single stations on secondary and tertiary streams draining areas averaging 8 to 15 square kilometres. Four of the sampled catchments contain gold mineralization and are undisturbed by large-scale placer or bedrock mining activity. Local geology of the anomalous drainages and some site characteristics are summarized in Table 6-3-1. Three additional stations were established at 2-kilometre intervals along one of the anomalous streams (Fedral Creek) to examine the downstream dispersion characteristics of gold for each sampling method. The remaining drainages sampled are assumed to represent background concentrations of gold, based on the absence of reported occurrences of any economic minerals in a readily accessible, well-explored area.

At all stations, replicate samples were collected from high and low energy environments, characterized by course gravel and fine gravel to sands respectively. Higher energy environments (for example, heads of stream bars), which are known to favour the accumulation of higher density minerals, were typical heavy mineral sample locations. Conversely, the less energetic environments (for example, tails of stream bars), which favoured the rapid collection of fine sands, were representative of conventional stream sediment sites. Plates 6-3-1 and 6-3-2 illustrate the contrasting textures of samples collected from high and low energy environments respectively. Four replicate samples were collected from each environment at sample stations in anomalous streams, and two were collected from each environment in background streams. All replicate samples within a given station were collected, on average, over a 25-metre segment of the stream course.

Samples were shovelled or scooped directly into an 11-litre steel pail, wet-sieved to -20 (1 millimetre) and stored in labelled plastic bags. Sample weight averaged about 14 kilograms wet.

Each site was photographed and a number of general observations recorded, including stream width, weight of material processed and elapsed time for sample collection. Sketches of sites included channel and bar configurations, and sample locations (Figure 6-3-2).

TABLE 6-3-1
DESCRIPTION OF SAMPLED ANOMALOUS STREAMS
(*see* Figure 6-3-1 for locations)

Stream: **NTS Sheet:** **Draining Mineral Occurrence:**	**Local Geology and Gold Mineralization**	**Site Characteristics[1]**
Fedral Creek 93L/10E Dome Mountain	Au-Cu-Pb quartz veins near upper contact of the Telkwa Formation	D = 3 km R = 200 m A = 10 km^2
Richfield Creek 93L/09W Topley-Richfield	Au-Zn-Pb quartz carbonate veins in Hazelton volcanics	D = 3 km R = 175 m A = 15 km^2
Cabinet Creek 93L/11E Hunter Basin	Au-Cu-Ag quartz veins cutting Hazelton volcanics	D = 4 km R = 800 m A = 18 km^2
Glacier Gulch 93L/14W Glacier Gulch (North and Bismuth)	Au-Mo-W-Bi quartz veins sheetings and stockworks	D = 3 km R = 250 m A = 12 km^2

[1] D = Distance downstream from mineralization.
R = Relief from mineralization to sample site.
A = Sampled drainage area.

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British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

PROPOSED SAMPLE PROCESSING

Sample preparation by a commercial laboratory will involve a series of splitting, sizing and heavy liquid separations to obtain samples which are representative of conventional stream and heavy mineral samples (Figure 6-3-3).

Initially, all -20 mesh bulk samples will be dried and then separated into 1/8 (1 to 1.5 kilograms approximately) and 7/8 (8 to 10 kilograms approximately) splits. Processing of the larger split will involve wet-sieving through a -60 mesh screen, a density separation by a two-stage heavy liquid treatment (tetrabromethane, S.G. = 2.96 and methylene iodide, S.G. = 3.3), and then sizing to prepare four heavy mineral concentrates (-60 + 150, -150 + 200, -200 + 270 and -270 fractions). Processing of the smaller split will involve dry-sieving through -80 mesh to prepare a typical stream sediment sample.

FUTURE WORK

Processed samples will be weighed into plastic vials for estimation of gold and associated elements by neutron activation analysis at a commercial laboratory. Analytical results are expected early in 1987.

Results from this study will be used to assist in (1) quantifying the risks and benefits of re-analysis of archived Regional Geochemical Survey -80 mesh (<177 microns) stream sediment pulps for gold, and (2) selection of an appropriate stream sediment sampling technique for gold in future surveys. An Open File Report describing the results will be available in 1987.

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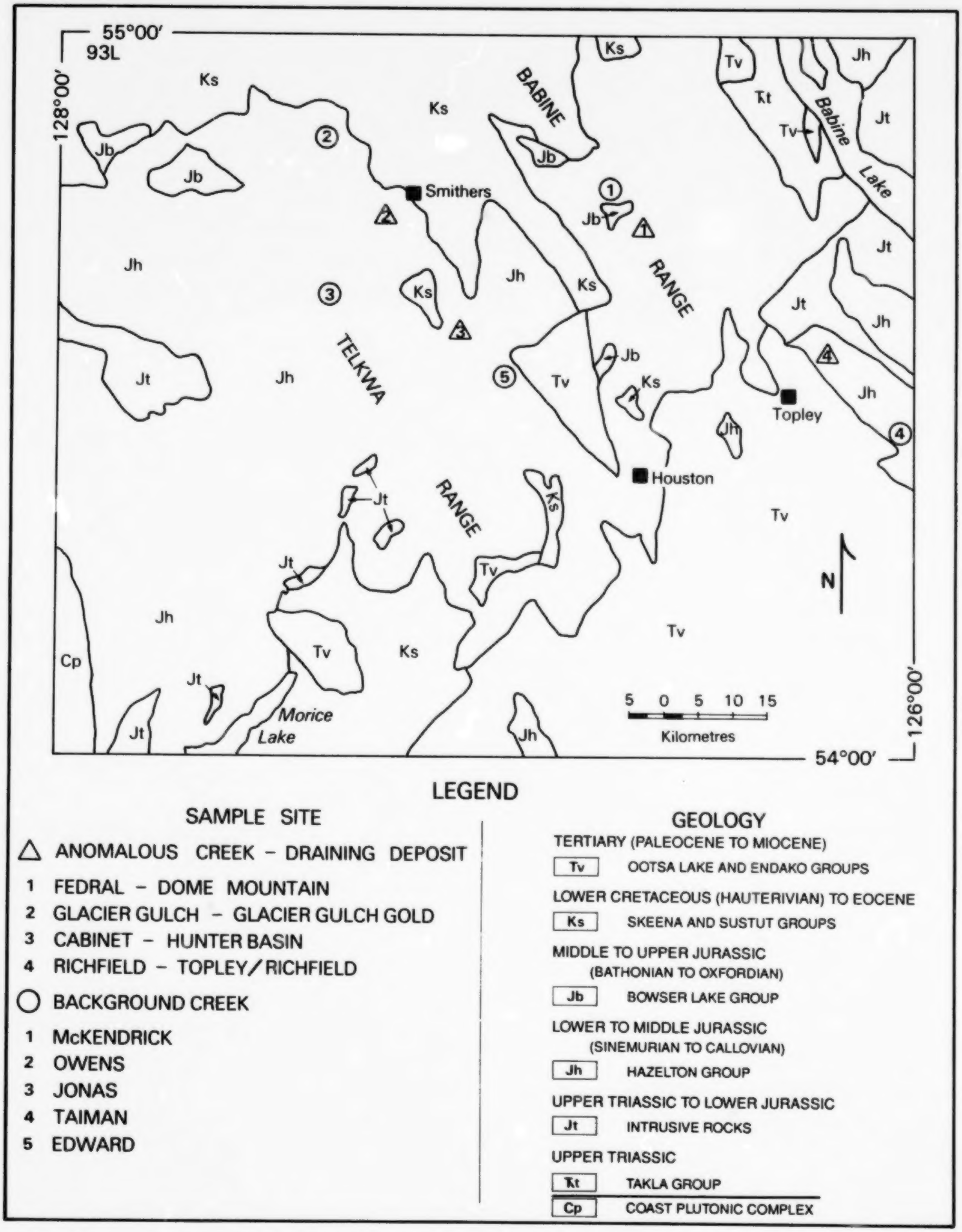
55°00′
93L
128°00′
126°00′
54°00′
BABINE RANGE
TELKWA RANGE
Babine Lake
Morice Lake
Smithers
Houston
Topley
Ks
Jb
Jh
Jt
Tv
Ŧt
Cp
N
5 0 5 10 15
Kilometres
LEGEND
SAMPLE SITE
△ ANOMALOUS CREEK – DRAINING DEPOSIT
1 FEDRAL – DOME MOUNTAIN
2 GLACIER GULCH – GLACIER GULCH GOLD
3 CABINET – HUNTER BASIN
4 RICHFIELD – TOPLEY/RICHFIELD
○ BACKGROUND CREEK
1 McKENDRICK
2 OWENS
3 JONAS
4 TAIMAN
5 EDWARD
GEOLOGY
TERTIARY (PALEOCENE TO MIOCENE)
Tv OOTSA LAKE AND ENDAKO GROUPS
LOWER CRETACEOUS (HAUTERIVIAN) TO EOCENE
Ks SKEENA AND SUSTUT GROUPS
MIDDLE TO UPPER JURASSIC (BATHONIAN TO OXFORDIAN)
Jb BOWSER LAKE GROUP
LOWER TO MIDDLE JURASSIC (SINEMURIAN TO CALLOVIAN)
Jh HAZELTON GROUP
UPPER TRIASSIC TO LOWER JURASSIC
Jt INTRUSIVE ROCKS
UPPER TRIASSIC
Ŧt TAKLA GROUP
Cp COAST PLUTONIC COMPLEX

Figure 6-3-1. Sample site locations and general geology of the Smithers map sheet area.

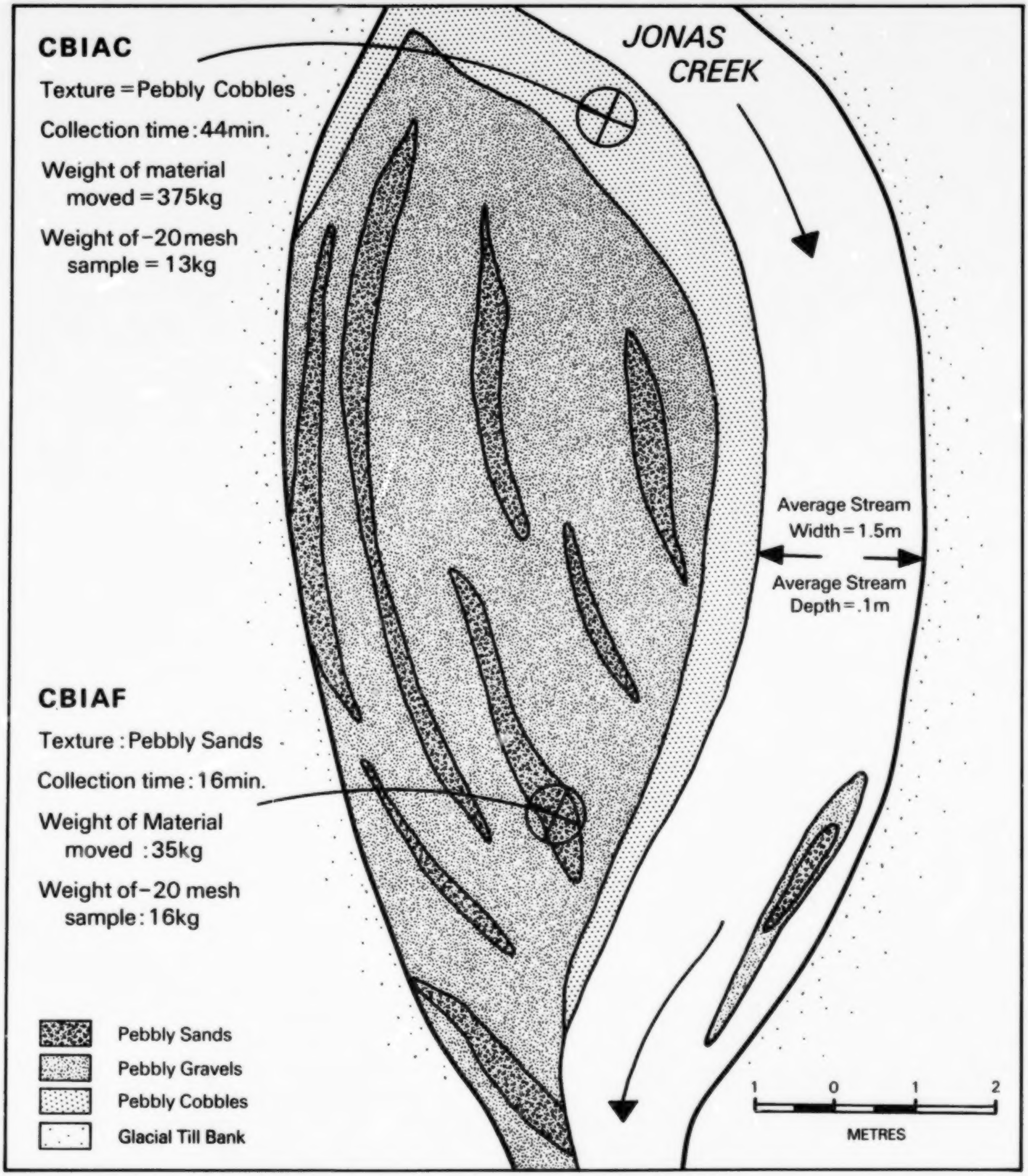
CBIAC
Texture = Pebbly Cobbles
Collection time: 44min.
Weight of material moved = 375kg
Weight of -20 mesh sample = 13kg
JONAS CREEK
Average Stream Width = 1.5m
Average Stream Depth = .1m
CBIAF
Texture : Pebbly Sands
Collection time: 16min.
Weight of Material moved : 35kg
Weight of -20 mesh sample: 16kg
Pebbly Sands
Pebbly Gravels
Pebbly Cobbles
Glacial Till Bank
1
0
1
2
METRES

Figure 6-3-2. Detailed sketch map and sampling statistics for two bulk sediment samples collected from Jonas Creek.

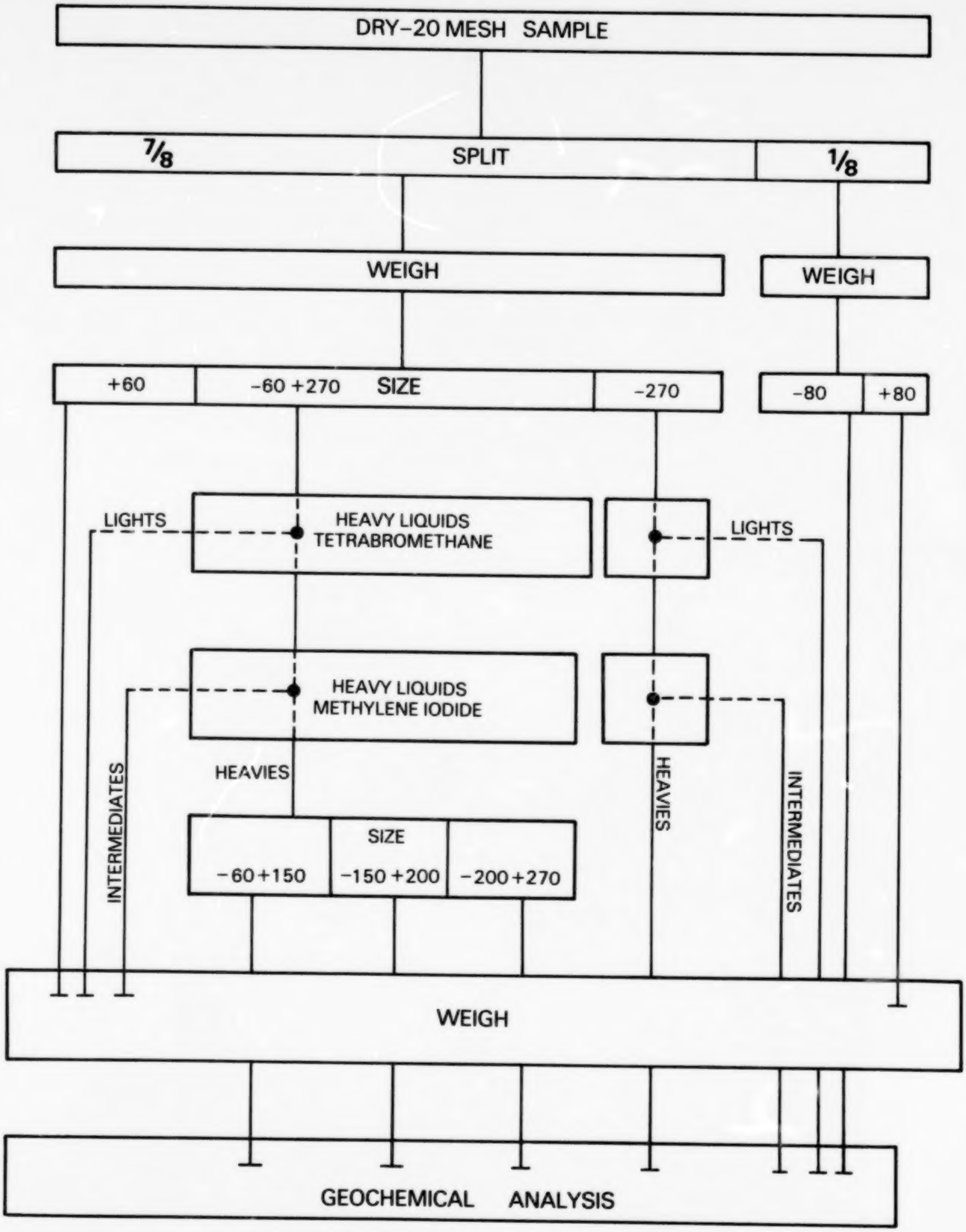
DRY–20 MESH SAMPLE
7/8
SPLIT
1/8
WEIGH
WEIGH
+60
–60 +270
SIZE
–270
–80
+80
LIGHTS
HEAVY LIQUIDS
TETRABROMETHANE
LIGHTS
HEAVY LIQUIDS
METHYLENE IODIDE
INTERMEDIATES
HEAVIES
HEAVIES
INTERMEDIATES
SIZE
–60 +150
–150 +200
–200 +270
WEIGH
GEOCHEMICAL ANALYSIS

Figure 6-3-3. Bulk sample processing scheme.

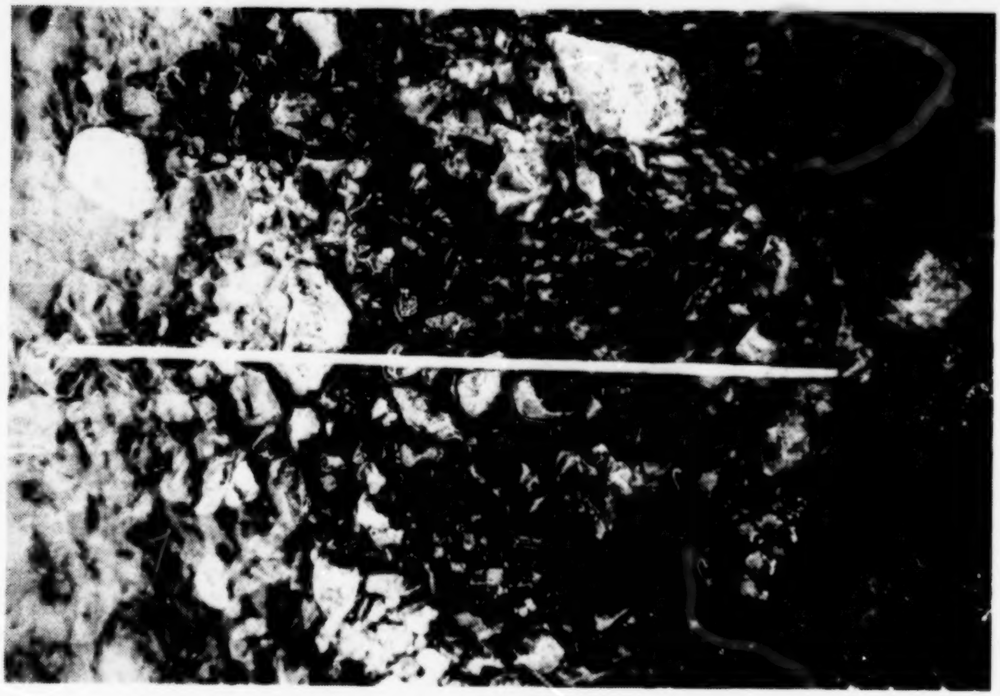

Plate 6-3-1. Typical textural characteristics of higher energy environments selected for bulk sediment sampling. Site photo of sediment sample GAICC.

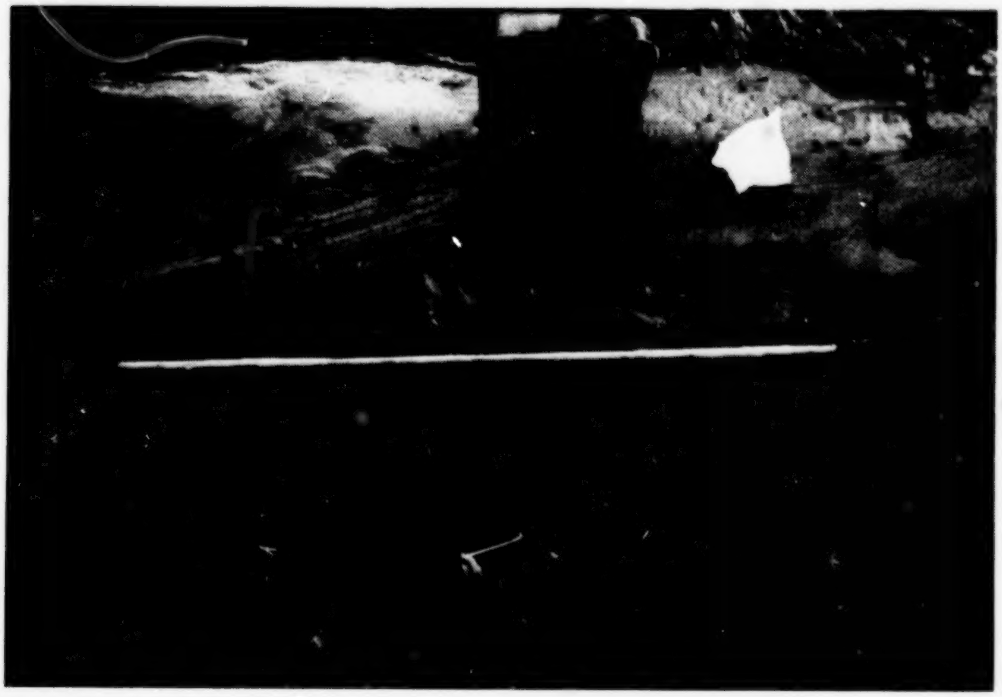

Plate 6-3-2. Typical textural characteristics of lower energy environments selected for bulk sediment sampling. Site photo of sediment sample GAICF. Note scale in both photos is 50 centimetres.

SEASONAL VARIATION OF GOLD CONTENT OF STREAM SEDIMENTS HARRIS CREEK, NEAR VERNON*
(82L/02)

By S. Day and K. Fletcher
Department of Geological Sciences
The University of British Columbia

INTRODUCTION

Concentrations of gold in stream sediments can reflect both the presence of gold mineralisation in a stream basin or, like other heavy minerals (Fletcher *et al.*, in press; Saxby and Fletcher, 1986 and in press), the influence of local hydraulic conditions on its differential transport and segregation from the less dense components of the sediment. In extreme cases, these processes lead to the formation of placer deposits. However, they are more often encountered by the exploration geologist as a major source of variability and difficulty in repeating results of geochemical or heavy mineral surveys for gold. Here we present results of the first phase of an ongoing study of seasonal variations in gold content of a single anomalous stream. Because high density minerals, such as magnetite, tend to accumulate with gold during sediment transport and are less susceptible to the analytical errors associated with very rare particles of gold, it is also helpful to consider data for the magnetic mineral fraction.

LOCATION

Harris Creek rises in the Okanagan Highlands east of Vernon and flows north through Lumby (Figure 6-4-1). It was selected for this study because it has exceptionally high gold concentrations in the present day stream bed and is easily accessible, allowing trouble-free removal of bulk sediment samples.

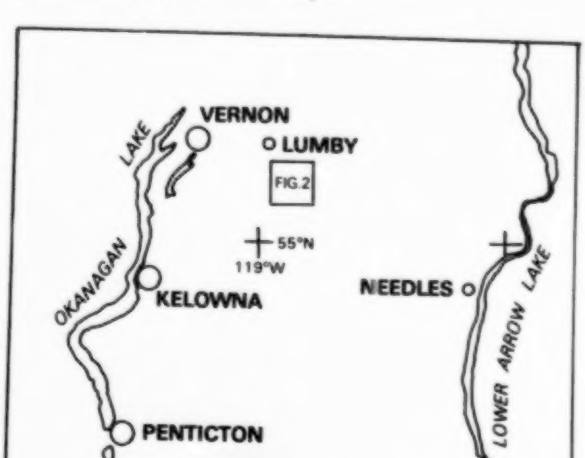

Figure 6-4-1. Location of Harris Creek.

STUDY REACH

A study reach, approximately 2 kilometres long, 25 kilometres from the watershed, was selected for detailed sampling (Figure 6-4-2). The major source of gold in the drainage sediments is unknown, but is probably at least 3 kilometres upstream from the uppermost sampling location. The reach has a fairly constant energy slope of 0.03 and there are no major confluences. The channel shows low sinuosity meandering with well-developed gravel point bars, which become channel bars during peak spring discharges (>10 cubic metres per second). The south bank is underlain by resistant granodiorite which produces bedrock riffles on south convex bends; the north bank is underlain by recessive argillite and basaltic volcanics.

SAMPLING METHODOLOGY

In an initial study of Harris Creek, Day and Fletcher (in press) found that at least 60 kilograms of minus 10-mesh (2 millimetres) sediment were needed to provide sufficient −150+200 and

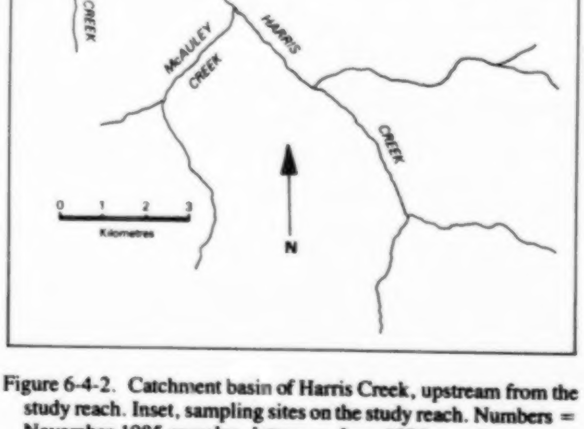

Figure 6-4-2. Catchment basin of Harris Creek, upstream from the study reach. Inset, sampling sites on the study reach. Numbers = November 1985 samples, letters = June 1986 samples.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

−200+270-mesh sediment to give relative errors better than ±50 per cent at the 95 per cent confidence level for the gold analyses. This estimate is derived from the Poisson distribution and corresponds to having approximately 20 particles of gold in the fractions being analysed. The standard sample in this study therefore consisted of 60 kilograms (dry weight) of minus 10-mesh sediment, an amount which fills two 23-litre pails.

In November 1985, six samples were taken at three point-and-channel bar sites on the study reach (Figure 6-4-2). In the following June, a slightly greater length of the stream was sampled with eight samples collected from four sites (Figure 6-4-2). The three initial locations could not be resampled as discharges were much greater in the spring, due to meltwater runoff. Samples were taken at the upstream and downstream ends of bars, representing erosional and depositional environments respectively. Field sampling technique consisted of selection of an area of stream bed having homogeneous texture, followed by wet-sieving of sediment through a 2-millimetre nylon sieve. Loss of fine sediment from the sample was prevented by catching the overflow from the pail in an aluminum tub. The +2-millimetre fraction was retained and weighed. As much as 300 kilograms of sediment were processed at each erosional site but on average, only 60 kilograms were processed at the depositional sites (Table 6-4-1).

TABLE 6-4-1.
TOTAL SEDIMENT PROCESSED FOR
EACH SAMPLE TO YIELD
23 LITRES OF MINUS 10-MESH

November 1985			June 1985		
Number	E/D[1]	Weight (kg)	Number	E/D	Weight (kg)
16	E	243	M1	D	70
17	D	162	M2	E	147
18	D	70	A1	D	62
19	E	386	A2	E	231
20	D	57	C1	D	134
21	E	475	C2	E	282
			K1	D	68
			K2	E	236

[1] E = erosional; D = depositional.

SAMPLE PROCESSING

Samples were dry-sieved to eight fractions, using a Rotap, then manually wet-sieved to clean up the finer fractions. Heavy mineral concentrates were prepared for two fractions (−150+200-mesh and −200+270-mesh) using methylene iodide (specific gravity = 3.3) followed by separation of magnetic minerals with a hand magnet. Magnetic minerals were separated from −70+100-mesh and −100+150-mesh fractions using an induced magnetic separator and hand magnet without first producing a heavy mineral concentrate. Magnetic minerals were removed from minus 270-mesh material by creating a slurry with water and stirring with a magnetic bar. Nondestructive neutron activation analysis was used to determine gold in nonmagnetic heavy mineral concentrates of the −150+200 and −200+270-mesh fractions and nonmagnetic minus 270-mesh sediment.

RESULTS AND DISCUSSION

When interpreting the data, it should be noted that samples taken from erosional environments consist mostly of material taken from the stream bed subsurface and are considerably finer than the surface layer in contact with fast-flowing water. During winnowing, fine sediment is removed from the surface, creating an armour which prevents erosion of the subsurface. The sample is therefore not representive of the stream bed produced by stream processes acting at the time of sampling. Conversely, fine sediment samples taken from depositional sites principally represent a composite of products of erosional processes that occurred immediately upstream from the sampling location during the waning stage of the last freshet.

Magnetic mineral concentrations are best summarized as means and coefficients of variation (CVs) for the sites sampled in each season (Table 6-4-2). Although abundance of magnetic minerals is similar in minus 270-mesh material from both environments, results indicate that depositional sites show less variability in abundance of magnetic minerals between fractions. In particular, depositional sites do not contain the high concentrations of magnetic minerals found in the coarser sized fractions from erosional sites. This probably reflects a lack of supply to depositional sites as coarse magnetic mineral grains are trapped and concentrated at erosional sites. Conversely, as described in other heavy mineral studies (Saxby and Fletcher, in press), finer magnetic minerals are less susceptible to density segregation and become more uniformly distributed between environments. This is also consistent with the well-developed trend for magnetic mineral CVs for both environments which shows a systematic decrease from coarse to fine size fractions in the November samples. Failure to detect this trend in June suggests that immediately after the spring meltwater flood, the sediments have not yet developed systematic grain size-density relationships.

TABLE 6-4-2.
SUMMARY STATISTICS FOR MAGNETIC
MINERAL CONCENTRATIONS

	November 1985[1]				June 1986[2]			
	Erosion		Deposition		Erosion		Deposition	
Fraction	$\bar{X}$[3]	CV[4]	$\bar{X}$	CV	$\bar{X}$	CV	$\bar{X}$	CV
−70+100	10.9	91	2.5	50	13.9	48	1.7	33
−100+150	10.5	73	3.9	34	12.4	39	2.8	43
−150+200	6.1	64	3.0	15	9.9	58	3.2	48
−200+270	4.2	42	2.4	8	4.9	42	3.1	19
−270	2.4	24	1.6	33	1.4	35	1.1	33

[1] Three sites (six samples).

[2] Four sites (eight samples).

[3] Mean of magnetic mineral concentrations (%) calculated on untransformed data.

[4] Coefficient of variation (%).

Data for gold are arranged in the same way in Table 6-4-3. For the −150+200 and −200+270-mesh fractions, it is apparent that although gold is not eroded and transported to depositional sites, average concentration differences (up to approximately 100 times) are very much greater than those associated with even the coarsest magnetite (Table 6-4-2). This is consistent with earlier observations that the tenor of heavy mineral enrichments increases with the density of the mineral concerned (Saxby and Fletcher, in press).

Coefficients of variation for gold include not only between-site variability (reflecting the wide range of hydraulic conditions observed in depositional environments), field sampling and laboratory processing errors, but also high errors associated with sampling of rare grains as described by the Poisson distribution. Hence, coefficients of variation greater than 100 per cent, without obvious seasonal trends, are associated with the low gold concentrations and extreme rarity of gold in −150+200-mesh and −200+270-mesh

TABLE 6-4-3.
SUMMARY STATISTICS FOR GOLD CONCENTRATIONS

	November 1985[1]				June 1986[2]			
	Erosion		Deposition		Erosion		Deposition	
Fraction	$\bar{X}^{3}_{L}$	CV[4]	$\bar{X}_{L}$	CV	$\bar{X}_{L}$	CV	$\bar{X}_{L}$	CV
−150+200	170	14	4.5	134	383	18	2.2	192
−200+270	122	23	1.8	449	454	38	4.0	134
−270	21	25	24.0	30	27	32	6.6	34

[1] Three sites (six samples).

[2] Four sites (eight samples).

[3] Mean of gold concentrations (ppb) calculated for whole fraction using log transformed data.

[4] Coefficient of variation (%).

sediments from depositional environments. In contrast, despite their low gold content, CVs for gold in minus 270-mesh sediments are only about 30 per cent. As discussed by Day and Fletcher (in press), this reflects the large number of minus 270-mesh gold particles (average diameter 20μ) required to provide even these low gold concentrations. Thus, providing anomalous concentrations of gold are present in this size range, minus 270-mesh sediment can provide an adequate exploration sample without the need to prepare a heavy mineral concentrate.

Although depositional sites show no obvious trends in magnetite and gold content between November and June, average concentrations in all but the minus 270-mesh fraction of erosional sites show notable increases from two to fourfold for gold. However, because of differences in sampling sites caused by high water in June, there is insufficient evidence to determine how these differences reflect true seasonal variations in erosion and deposition. Bulk sediment samples are now being collected, at regular time intervals from erosional and depositional environments associated with a single bar, in an attempt to resolve this problem.

CONCLUSIONS

Results at this early stage show that:

(1) The highest concentrations of high density minerals are found in erosional environments. A large volume of sediment (up to 450 kilograms) must be processed in order to obtain the sample.

(2) The lowest variability between sites and between erosional and depositional environments occurs in the minus 270-mesh sediment. This fraction can be conveniently analysed without preparation of a heavy mineral concentrate.

ACKNOWLEDGMENTS

Funding for this study was provided through an N.S.E.R.C. operating grant and the Canada/British Columbia Mineral Development Agreement.

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GEOCHEMICAL FOLLOW-UP OF RGS DATA ORIENTATION REPORT ON THE FIELD-SIEVED STREAM SEDIMENT SAMPLING METHOD BLACKWATER MOUNTAIN AREA*

(93G/2)

By S. Zastavnikovich

INTRODUCTION

The aim of this limited sampling survey was to investigate the benefits of field-sieved stream sediment sampling as a follow-up method to the Regional Geochemical Surveys (RGS), and as an inexpensive alternative to field panning and the costly heavy mineral separation methods.

The area selected for sampling is located east and south of Blackwater Mountain, northwest of Quesnel, where the 1984 RGS 12 identified a site highly anomalous in several trace elements, in a creek draining the southeastern flank of the mountain. Following release of the RGS data, A.J. Boronowski followed up the anomaly with a program of high density field-panned sampling and heavy liquid and magnetic separation of the panned stream sediments (Boronowski, 1986, page 115). The survey confirmed and further defined the multi-element anomaly and also established the presence of highly anomalous gold values in the concentrates. Due to extreme variability in gold content between adjacent sites, ranging

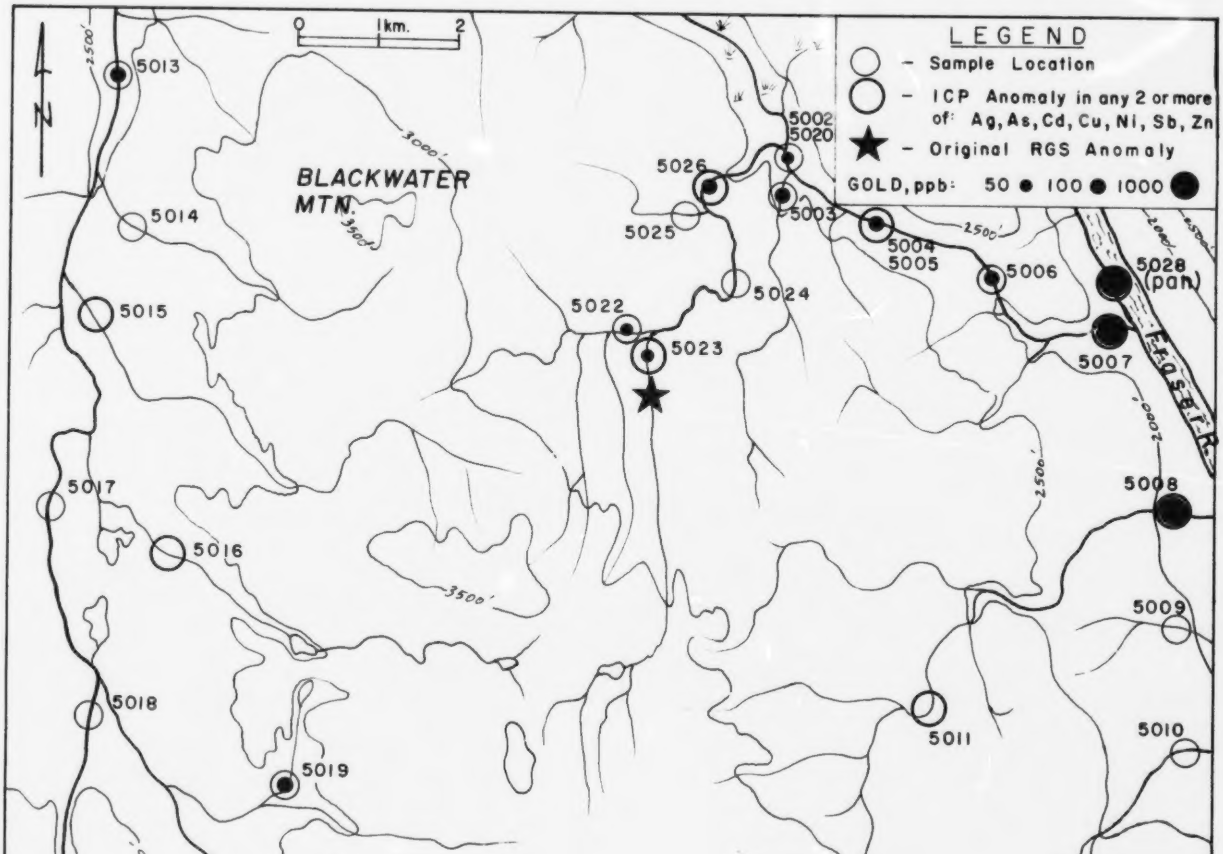
0
1km.
2
N
2500'
3000'
3500'
2000'
BLACKWATER MTN.
Fraser R.
LEGEND
○ - Sample Location
◯ - ICP Anomaly in any 2 or more of: Ag, As, Cd, Cu, Ni, Sb, Zn
★ - Original RGS Anomaly
GOLD, ppb: 50 ● 100 ● 1000 ●
5002
5020
5003
5004
5005
5006
5007
5008
5009
5010
5011
5013
5014
5015
5016
5017
5018
5019
5022
5023
5024
5025
5026
5028 (pan)

Figure 6-5-1. Topographic 1:50 000-scale sample location and anomaly map.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

from undetectable to 21 000 parts per billion (ppb), no attempt was made to relate the gold to the trace element values.

In 1986 the writer collected six sediment samples downstream from the original RGS anomaly at approximately 2-kilometre intervals to the mouth of the main stream. Additional samples were collected on neighbouring drainages for comparison purposes.

The samples were sieved through an 80-mesh screen and analysed for trace elements by inductively coupled plasma (ICP), and for gold by geochemical fire assay and atomic absorption (AA). Field and laboratory sample duplicates were inserted according to the sampling standards established for the RGS (Garrett, 1974). Analytical results, a manganese-iron graph and a sample location and anomaly map are included as figures in this article.

GENERAL PHYSIOGRAPHY AND GEOLOGY

The original RGS anomalous sample 841053 is located at the mouth of a headwaters tributary to a larger stream draining the eastern flank of Blackwater Mountain easterly toward the Fraser River (*see* Figure 6-5-1). The surficial geology map (Tipper, 1971) shows the regional ice movement in the area to be from south to north, though on the local scale it may have also moved downslope to the east.

The drainage basin is underlain by argillites and greenstones of the Permian Cache Creek Group, probably intruded by Permian to Triassic ultramafics, as suggested by elevated nickel values. Oligocene Endako Group basic volcanic rocks outcrop on the peak of Blackwater Mountain and further west.

FIELD AND ANALYTICAL METHODS

Wet-sieving the stream sediments through a stainless steel sieve in combination with a perforated pan device helped isolate lithic silt from organic debris, providing sample consistency between sites. The writer used a 40-mesh screen, but other screen sizes would serve equally well. Trace-metal values in sediment grab samples are usually higher than those in field-sieved samples from the same sites, due to scavenging by organics, but are much less repeatable and more difficult to interpret.

A total of 25 sediment samples was collected from the anomalous drainage and neighbouring streams. Samples 8693G-5001 and 5021 are internal laboratory duplicate splits of field samples 5003 and 5020 respectively. Samples 5004 and 5005 are field duplicates for external checking. Samples 5002 and 5020 were taken at the same site, but from low-water and high-water environments respectively. Sample 5028 is a panned concentrate of Fraser River sand. Except for sieving through an 80-mesh screen, no further sample processing was done prior to analysis.

The samples were analysed at the Min-En Laboratory in North Vancouver for 26 elements by ICP after a nitric-perchloric acid digestion, and for gold by fire assay preconcentration of a 15-gram sample, followed by aqua regia digestion and extraction with methyl iso-butyl ketone prior to analysis by atomic absorption (Table 6-5-1).

DISCUSSION

The sampled area overlaps the designated placer area along the Fraser River thus it is not surprising that high gold values are encountered in the stream silt samples. Results indicate the amount of gold in the sediments increases in an easterly direction, toward the Fraser River valley, suggesting that most of the gold is of placer origin. This is also suggested by the consistent distribution of gold between the main fork of the sampled stream and the river. Natural traps for heavy minerals in the streams were sampled preferentially and it is rewarding to see the continuity of gold values in unpanned samples, and the reliability of the 15-gram sample in the laboratory.

Geochemical trace element sample analysis is necessary to help distinguish gold values of placer origin from those due to bedrock mineralization. Strong placer gold values may mask weak responses related to mineralized quartz veins in bedrock. Such mineralization generally yields subdued, though detectable trace element responses, but much more detailed sampling would be needed to detect them. Provided that a high sampling standard is maintained, the ICP multi-element analytical method is particularly useful as it provides both lithology and mineralization-related information in terms of elemental ratios, which help to identify true rather than purely statistical anomalies. Poor sampling technique totally obscures such relationships.

For example, the dependence of vanadium values on those of iron is readily apparent in the analytical results. Other elemental correlations are present, though somewhat less obvious. Recognition of such patterns leads to the recognition of anomalies based on multi-element ratios rather than values for a single element. Using manganese and iron alone as a first approximation for an X/Y plot, the manganese/iron versus zinc graph, Figure 6-5-2, illustrates that samples 5024 and 5026 are still anomalous in zinc, indicating the length of the dispersion train from the highly anomalous sample 5023. The graph also indicates that sample 5011 is somewhat anomalous or enriched in zinc, but that sample 5018 is less so, though they have identical analytical values for zinc.

Other helpful patterns based on the multi-element analysis can be derived by grouping samples with similar trace element geochemistry, then comparing their lithology and environment. Thus sample numbers 5008 and 5015 have similar trace element patterns to the panned river sand sample 5028, implying the presence of heavy minerals, such as can be present in thick, well-reworked, glacial gravels.

The slope of the manganese/iron line on the graph indicates the fundamental lithological ratio between the two elements, though too few samples were taken to establish this clearly. Samples plotting far above the line represent environmental manganese enrichment, such as encountered in swampy terrain. Samples plotting far below the line are indicative of environmental manganese depletion, such as occurs in reworked glacial sediments.

These brief examples from this very limited follow-up study illustrate both the simplicity and the complexity involved in the interpretation of geochemical results, and the absolute necessity for high-quality sampling.

CONCLUSIONS

(1) The sampling of stream sediments by wet-sieving in the field, using a sieve and perforated pan device, greatly improves the sample quality and increases the interpretability of the analytical results.

(2) Experienced sampling site selection, combined with field-sieving and geochemical fire assay preconcentration of a minimum 15-gram laboratory subsample, can effectively bypass the expensive heavy liquid separation methods in geochemical analysis for gold.

(3) The ICP method of trace element analysis is particularly well suited to stream sediment sampling studies as it inexpensively provides a wealth of both lithological and mineralization-related information.

(4) In areas where gold of placer origin is present in the streams, detailed high-quality sediment sampling is necessary to detect potential gold mineralization in bedrock, by measuring subdued, but detectable trace element enrichment.

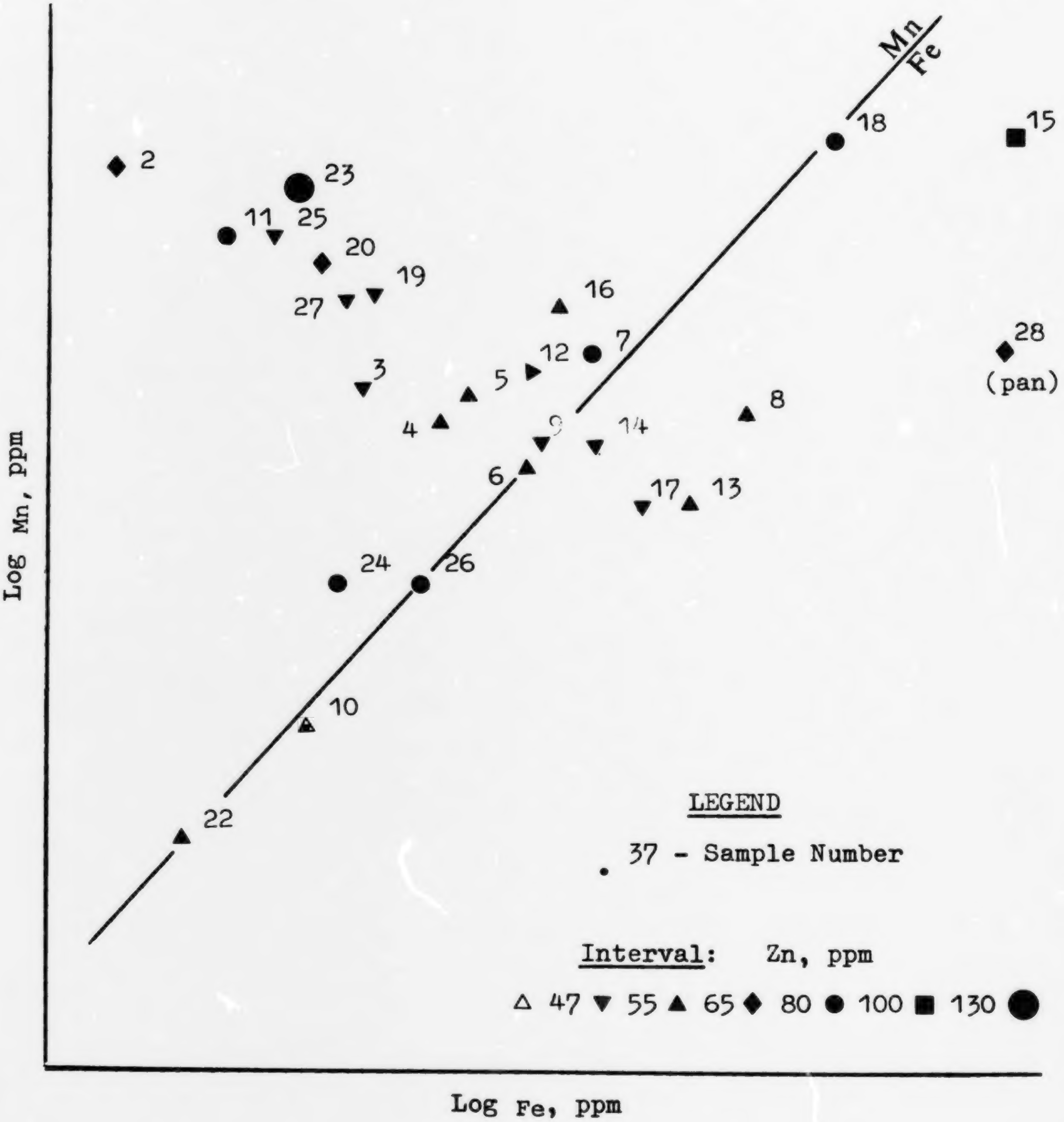

Figure 6-5-2. Mn/Fe versus Zn graph.

TABLE 6-5-1. ANALYTICAL RESULTS
(Values in p.p.m. except Au)

Sample No.	K	Li	Mg	Mn	Mo	Na	Ni	P	Pb	Sb	Sr	Zn	Au-PPB
8693G-5001	420	6	5040	408	7	80	25	490	21	8	20	60	315
8693G-5002	510	8	4790	631	5	90	22	370	12	2	23	69	3
8693G-5003	430	6	4770	388	7	80	22	450	19	7	18	53	220
8693G-5004	390	5	4290	374	6	90	18	450	18	9	20	59	395
8693G-5005	420	5	4700	396	7	100	21	470	15	8	21	64	280
8693G-5006	320	5	5180	338	7	100	20	460	21	10	22	56	245
8693G-5007	520	5	6190	429	8	140	28	440	23	13	29	82	1450
8693G-5008	450	6	5630	380	10	120	22	510	20	16	23	63	3300
8693G-5009	430	4	4670	362	6	140	18	420	14	7	22	52	25
8693G-5010	860	6	4700	201	4	120	10	1020	9	2	25	37	5
8693G-5011	570	7	4410	556	5	80	30	430	10	2	20	83	3
8693G-5012	430	4	5010	415	5	160	15	410	9	5	20	55	6
8693G-5013	340	4	4140	314	5	200	6	410	7	7	16	58	105
8693G-5014	510	4	5710	351	7	180	20	430	13	8	24	51	5
8693G-5015	350	3	6780	668	9	110	11	420	13	21	15	103	3
8693G-5016	640	6	7100	476	6	220	19	410	9	2	31	57	4
8693G-5017	330	3	4590	311	5	160	11	350	7	6	16	52	4
8693G-5018	470	3	4310	660	5	410	6	460	2	5	36	82	7
8693G-5019	380	4	5550	493	5	150	25	370	9	3	20	52	160
8693G-5020	460	6	4370	522	6	90	18	420	12	4	20	69	14
8693G-5021	450	6	4390	508	6	90	19	460	11	5	19	71	75
8693G-5022	430	4	3080	160	4	110	12	330	3	1	23	57	62
8693G-5023	620	8	4350	591	6	90	30	400	14	4	25	165	55
8693G-5024	470	5	3810	268	5	90	17	410	10	3	22	87	16
8693G-5025	560	8	4770	547	5	140	17	350	10	1	23	52	12
8693G-5026	410	4	3760	265	5	90	16	420	13	5	19	86	158
8693G-5027	570	4	4130	479	4	170	16	510	6	1	34	54	3
8693G-5028	110	2	3730	423	18	20	16	500	52	40	23	69	95000

Sample No.	Ag	Al	As	B	Ba	Be	Bi	Ca	Cd	Co	Cu	Fe	V
8693G-5001	0.4	5800	58	11	70	3.8	4	3980	2.2	6	19	55410	81.1
8693G-5002	0.3	7520	7	5	103	2.2	2	4200	3.2	5	23	33950	29.3
8693G-5003	0.4	5870	49	7	71	3.7	3	3870	3.0	6	19	59300	86.7
8693G-5004	2.4	5770	54	5	79	4.0	2	3780	2.6	6	18	66930	95.2
8693G-5005	1.5	6260	64	7	77	3.9	4	4160	2.0	7	21	70730	98.0
8693G-5006	0.6	5360	82	7	65	4.7	4	5230	3.3	7	24	79740	117.1
8693G-5007	0.7	6680	80	10	114	5.0	5	6830	4.5	9	41	90380	110.9
8693G-5008	0.8	684.0	98	10	124	6.0	4	4630	4.0	9	20	124330	173.0
8693G-5009	0.6	6990	37	8	85	3.5	2	4500	3.0	7	18	81680	93.6
8693G-5010	0.5	8100	1	5	92	2.3	1	8570	2.2	5	12	50920	61.3
8693G-5011	0.5	7720	1	6	103	2.5	1	2910	3.0	5	22	43310	46.5
8693G-5012	0.5	6830	6	6	101	2.8	1	3720	2.5	7	17	81090	73.6
8693G-5013	0.7	6410	2	6	83	2.6	1	3420	2.2	7	11	114100	106.1
8693G-5014	0.6	7890	26	9	94	3.8	1	3570	2.9	7	17	92840	96.1
8693G-5015	1.1	7050	74	14	105	6.1	1	3100	3.7	14	19	234150	239.2
8693G-5016	0.6	14160	1	15	86	2.3	1	5330	4.2	7	25	84770	69.6
8693G-5017	0.6	6180	7	7	69	2.9	1	3370	2.5	6	12	100530	97.1
8693G-5018	0.9	14620	1	14	184	3.3	1	4670	3.1	10	12	152950	107.4
8693G-5019	0.5	7080	1	7	81	2.3	1	3480	2.6	6	17	58430	47.8
8693G-5020	0.6	6480	23	7	93	2.7	4	3960	2.5	5	19	52310	56.6
8693G-5021	0.6	6400	23	6	88	2.7	3	3970	2.8	5	18	52270	57.4
8693G-5022	0.5	8820	1	6	97	1.2	1	2880	1.8	3	15	39700	23.9
8693G-5023	0.6	9230	12	9	93	3.2	3	2760	3.9	7	28	50370	57.2
8693G-5024	0.6	7450	3	6	97	2.5	1	3060	2.2	5	20	54160	53.3
8693G-5025	0.5	9750	1	7	158	2.4	1	4140	3.0	6	20	46660	33.9
8693G-5026	0.6	6610	20	7	78	3.1	1	3310	2.6	6	17	65150	56.7
8693G-5027	0.5	12360	1	9	154	2.0	2	3910	2.6	5	21	55840	46.7
8693G-5028	3.4	3380	308	15	43	13.8	9	2770	4.9	14	14	210400	387.6

RECOMMENDATIONS

The wet-sieving field method of stream sediment sample collection should be seriously considered for future RGS work as it provides a high degree of uniformity of sampled material unobtainable by the standard "grab-and-run" sampling method.

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REGIONAL GEOCHEMICAL SURVEYS RGS 16 — WHITESAIL 93E* AND RGS 17 — SMITHERS 93L WEST-CENTRAL BRITISH COLUMBIA

By S. Zastavnikovich and W. M. Johnson

INTRODUCTION

During July and August 1986 the British Columbia Ministry of Energy, Mines and Petroleum Resources conducted two regional geochemical stream and lake sediment and water sampling surveys (RGS 16 and 17) covering the Whitesail and Smithers map sheets (Figure 6-6-1).

The Ministry organized and supervised all components of RGS 16. Sampling and analytical work were funded from the second year of the British Columbia/Canada Mineral Development Agreement (MDA). Data processing will be carried out by the Department of Energy, Mines and Resources (EMR), Ottawa.

The Ministry funded organization, supervision and sample collection activities for RGS 17 while EMR funded the sample preparation, analyses and data processing. Field supervision for both surveys was provided by S. Zastavnikovich under the direction of W. M. Johnson.

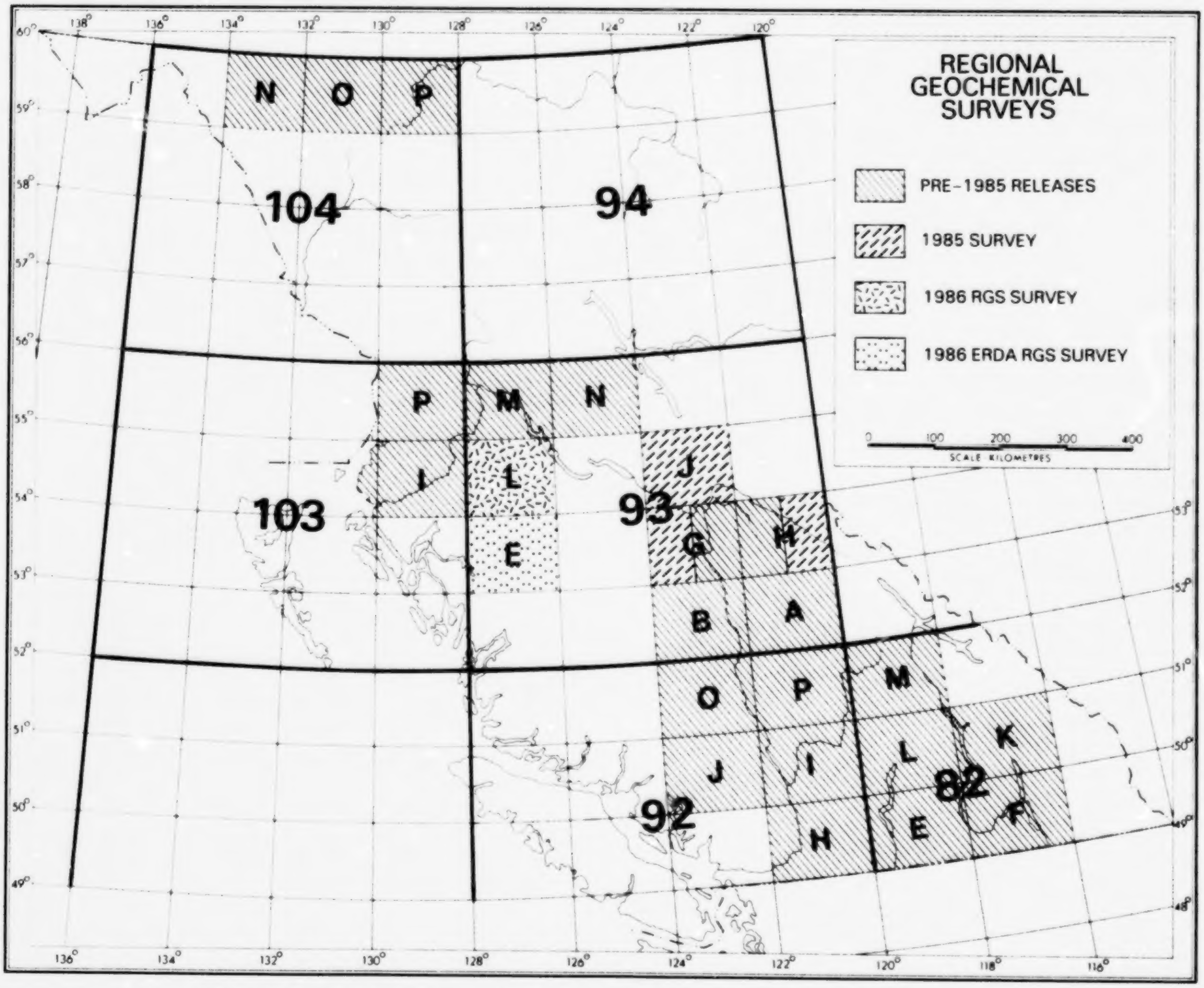
REGIONAL GEOCHEMICAL SURVEYS
▨ PRE-1985 RELEASES
▨ 1985 SURVEY
▨ 1986 RGS SURVEY
▨ 1986 ERDA RGS SURVEY
0 100 200 300 400
SCALE KILOMETRES
104
94
103
93
92
82
N O P
P M N
I L J
E G H
B A
O P M
J I L K
H E F

Figure 6-6-1. Location map for regional geochemical surveys carried out in British Columbia.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

SAMPLING DENSITY

Both surveys were concluded successfully within the contracted time frame. In the RGS 16 Whitesail map area, covering approximately 14 600 square kilometres, 1114 lake and stream sites were sampled, for an average density of one sample per 13.1 square kilometres. In the RGS 17 Smithers map area, covering approximately 14 400 square kilometres, 1093 lake and stream sites were sampled, also yielding an average density of one sample per 13.1 square kilometres.

When they become available, field and analytical data are processed, then plotted on maps at a scale of 1:250 000. Release of open file maps and summaries of field data and statistics is expected in June 1987.

METHODOLOGY

Field sampling for RGS 16 and RGS 17 was carried out by McElhanney Engineering Services Ltd. The contractor's crew consisted of an average of five men. Access was good on 93L, but poor on 93E due to mountainous terrain. Helicopters were used to access sample sites that could not be reached by truck, motorcycle, fixed-wing aircraft or boat. McElhanney contracted with Quasar Helicopters for helicopter support.

Water samples are analysed for uranium, fluorine and pH.

Stream sediments are analysed for zinc, copper, lead, nickel, cobalt, silver, manganese, iron, arsenic, molybdenum, tungsten, mercury, uranium, antimony, cadmium, barium and loss-on-ignition (LOI).

PHYSIOGRAPHY AND GEOLOGY

The Whitesail and Smithers map areas straddle the major physiographic boundary between the Coast Crystalline Belt and several subdivisions of the Intermontane Belt. Based on the subdivisions of Stuart S. Holland (1976), the Kitimat Ranges of the Coast Mountains occupy the southwestern third of the Whitesail sheet, while the Bulkley and the Babine Ranges of the Hazelton and Skeena Mountains form the northwestern half of the Smithers map area. The Nechako portion of the Interior Plateau occupies the eastern halves of both map sheets.

As described by Holland, the dominantly granitic Kitimat Ranges are characterized by round-topped, dome-like mountains with peaks from 2200 to 2500 metres and northerly facing cirques. These ranges have been over-ridden by the ice sheet, which left behind deep U-shaped river valleys with numerous hanging valleys in the steep walls and glaciers in the cirques.

The Bulkley, Babine and Tahtsa Ranges, representing the mountainous and highland portions of the Interior Plateau, are wedged between the Kitimat Mountains to the northwest and west and the low-lying Nechako Plateau to the east. The Bulkley River, draining northwards from Morice Lake into the Skeena River, separates the Hazelton Range from the Skeena Mountains. South of Morice Lake the drainage is eastward across the Nechako Plateau to the Fraser River system through the valleys of Tahtsa, Troitsa, Whitesail and Eutsuk Lakes, all at about 900 metres elevation. The serrate ridges and peaks are between 2100 and 2500 metres high, with glaciers in most northeast-facing cirques. The mountains are largely underlain by Mesozoic sedimentary and volcanic rocks intruded by isolated stocks and small granitic batholiths of Cretaceous age. The lakes occupy ice-modified valleys extending eastwards from within the granitic Coast Range Mountains onto the Nechako Plateau. Ice, which accumulated in the mountains to the west, flowed eastward across the Tahtsa Ranges and through the lake valleys onto the plateau and onwards toward the Rocky Mountains.

The Nechako Plateau is an area of low relief, with undissected expanses of flat or gently rolling country and a sparse stream drainage network. Over much of the plateau flat or gently dipping Tertiary lava flows cover the older sedimentary and volcanic rocks of the Takla and Hazelton Groups and intrusive rocks of Late Jurassic and Cretaceous age. From the Ootsa Valley the ice moved east and northeasterly, while along the Babine Valley it moved southeast, then veered to the northeast. Myriads of lakes occupy the plateau, ranging in size from small ponds to Babine Lake, and some 20 per cent of the samples taken were lake sediments.

In the southwestern section of the plateau, several round-topped mountains rise sharply above the general upland surface. These monadnocks on the Late Tertiary erosion surface result from the resistance to erosion of granitic stocks and their contact metamorphic aureoles. Granitic intrusions of Late Cretaceous and Early Tertiary age, often with associated porphyry copper and molybdenum mineralization, intrude Mesozoic volcanic and sedimentary rocks throughout the sampled area of the Intermontane Belt (Carter, 1981).

The physiographic extremes in the sampled area are reflected by wide variations in vegetation and drainage patterns. The plateau is heavily forested, except in areas flooded by numerous beaver dams along the dendritic stream valleys. The high mountains are characterized by herringbone drainage patterns. Steep valley sides were sometimes an obstacle to helicopter access.

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GAINS AND LOSSES OF ELEMENTS RESULTING FROM WALLROCK ALTERATION A QUANTITATIVE BASIS FOR EVALUATING LITHOGEOCHEMICAL SAMPLES*

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INTRODUCTION

Multi-element lithogeochemical analyses are increasingly widely used in the exploration for many types of gold deposits. To maximize the information gain from such data it is imperative to appreciate the chemical nature of unaltered country rock and altered wallrock of various origins, and to quantify the gains and losses of elements during the alteration process. An understanding of alteration history is important because many alteration zones are closely associated, spatially and genetically, with precious metal deposits.

A number of methods has been proposed to quantify the procedure for major and minor elements, including an assumption of constant volume, Barth's standard cell, and constant silica tetrahedra (Poldervaart, 1953).

The general assumption of constant volume is clearly incorrect. Barth's standard cell assumes that the number of oxygen atoms remains unchanged during metasomatism, whereas Poldervaart assumed that the number of silica tetrahedra is unchanged during the alteration process. Whatever the validity of these approaches to quantifying gains and losses, it is apparent that none of the preceding methods can be applied usefully in the case of carbonate-rich alteration haloes developed around gold-quartz veins enclosed in basic volcanic rocks. Such loss-gain situations can be dealt with by the use of a procedure presented initially by Gresens (1967) and later by Babcock (1973).

GRESENS METASOMATIC EQUATION

Gresens derived an ideal equation for calculating losses and gains of elements during metasomatism in terms of:

(1) Parent and product rock compositions,
(2) Specific gravities of the parent and product rocks,
(3) Volume change during metasomatism.

Gresens' equation will not be developed here but is reproduced with an explanation of terms.

$$X_n = a[f_V X_B (G_B/G_A) - X_A]$$

where X_n = loss or gain (grams of component n).
a = initial weight of rock A, commonly taken as 100 grams so that X_n will be weight per cent change of a component oxide.
f_V = volume ratio of product rock to parent rock.
X_A, X_B = weight fraction of component X in parent rock (A) and product rock (B).
G_A, G_B = specific gravities of parent rock (A) and product rock (B).

PROCEDURE

(1) Whole rock chemical analyses are required for both parent and product rocks to provide values for X_A and X_B.
(2) Specific gravities are measured for both parent and product rocks to provide values for G_A and G_B.
(3) Volume change during metasomatism is estimated as a proportion of the volume of product rock to a unit volume of parent rock. An estimate of f_V is obtained by examining the ratios of immobile elements such as TiO_2 and Al_2O_3. For example:
$f_V \approx (TiO_2)_A / (TiO_2)_B \approx (Al_2O_3)_A / (Al_2O_3)_B$

TABLE 6-7-1.
ABUNDANCE OF MAJOR ELEMENTS (WEIGHT PER CENT) FOR DDH 80-88, ERICKSON GOLD MINES LTD.

Element	80-88 – JH – 1	80-88 – JH – 2	80-88 – JH – 3	80-88 – JH – 4	80-88 – JH – 5	80-88 – JH – 6	80-88 – JH – 7
SiO_2	38.84	39.55	41.82	48.19	52.60	46.81	47.90
Al_2O_3	11.40	12.07	10.02	15.15	13.43	13.52	14.14
TiO_2	1.00	1.02	0.86	1.40	1.27	1.24	1.32
Fe_2O_3	8.69	8.93	8.97	10.61	10.38	10.87	11.33
MnO	0.15	0.15	0.18	0.16	0.19	0.17	0.16
MgO	5.87	5.60	5.98	5.58	5.83	7.14	7.31
CaO	11.21	10.40	10.43	6.23	4.36	11.19	10.40
Na_2O	0.30	0.28	0.10	0.01	0.01	1.40	2.11
K_2O	2.78	3.12	2.25	0.17	0.58	0.13	0.11
P_2O_5	0.12	0.07	0.07	0.10	0.10	0.10	0.10
LOI*	17.28	15.22	13.70	7.60	7.44	4.14	2.96
Total	97.64	96.41	94.38	95.20	96.19	96.71	97.84

* LOI = Total loss-on-ignition at 550°C and 1000°C.
Analyses done at the Department of Oceanography, The University of British Columbia.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

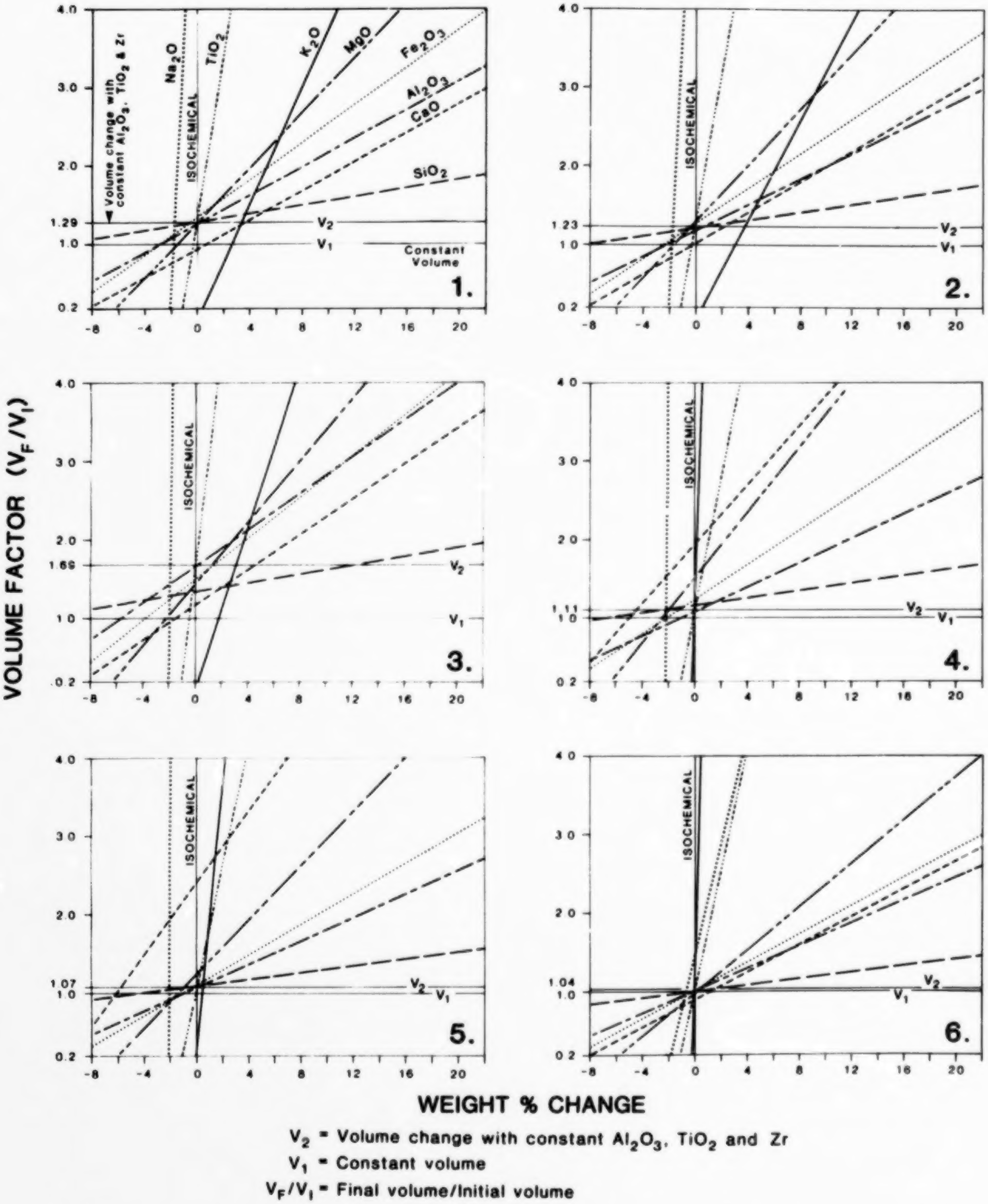

Figure 6-7-1. Composition-volume diagrams for six contiguous carbonatized basalt samples extending from the vein contact (1) outward to weakly altered wallrocks (6). Sample 3 is abnormal in containing a quartz veinlet. Legend for lines representing weight per cent element variations as a function of volume changes is shown for sample 1. Lines labelled V_1 are constant volume; lines labelled V_2 are the interpreted volume changes based on Figure 6-7-2. Element gains and losses are thus the intersections of line V_2 with individual element lines.

A value of 1 indicates no volume change whereas >1 indicates volume increase and <1 indicates volume decrease during metasomatism.

AN EXAMPLE — JENNIE VEIN, ERICKSON MINE

Carbonate alteration haloes developed at Erickson mine are described by Sketchley and Sinclair, 1987, Sketchley *et al.*, 1984, and Sketchley, 1986. Seven contiguous samples extending from the Jennie vein, through a carbonatized zone and into adjacent unaltered country rock, were analysed for whole rock chemistry by X-ray fluorescence. Results are listed in Table 6-7-1. Using the analytical data for a single alteration sample and the data for unaltered wallrock, it is simple to construct a composition-volume diagram (Babcock, 1973) as follows: for each element Gresens' metasomatic equation is solved for any two very different values of f_V, say 0.05 and 3.0. Thus, two points are known on the composition-volume metasomatic diagram and can be joined by a straight line as in Figure 6-7-1. Comparable straight lines can be constructed for each element. An estimate of the volume change, f_V, can be made from immobile elements and this can be drawn on the graph parallel to the composition axis. Intersections of the elemental straight lines with the volume factor line provide graphical quantitative estimates of the loss or gain of all elements with volume change taken into account. The losses and gains can be calculated more precisely by use of Gresens' formula. Similar diagrams can be constructed for each analysis of an unaltered rock. Six such diagrams, representing the six altered rock analyses (Table 6-7-1) from the Jennie vein alteration halo, are shown in Figure 6-7-1. They illustrate the variable manner in which individual rocks have reacted to metasomatism. The diagrams become somewhat complicated where substantial and variable losses and gains have occurred as in Figure 6-7-1(1) representing altered rock immediately adjacent to the vein. This pattern is in sharp contrast with the simplicity of Figure 6-7-1(6) which reflects only very minor metasomatic changes.

Volume changes vary from one sample to another. For the Jennie data reported here, we attempted to estimate the volume factor independently for each sample using three separate immobile variables, Al_2O_3, TiO_2 and Zr. Results shown in Figure 6-7-2A indicate that the assumption of immobility of these three components, although not perfect, is reasonably well satisfied. The approximate variation in volume change outward from the vein wall is shown in Figure 6-7-2B. In general, the amount of volume change decreases outwards from the vein toward unaltered country rock. The exception is a single sharp peak representing sample 3 which includes a quartz vein explaining this anomaly.

It is useful to examine individual elements as profiles of loss-gain versus position in an alteration halo (distance outward from vein wall). Results for eight elements are shown in Figure 6-7-3 where dramatic gains of K_2O and SiO_2 and losses of MgO, total Fe (as Fe_2O_3) and Na_2O are apparent from the alteration haloes. Interestingly, our calculations suggest a major rearrangement of CaO in the alteration halo, perhaps with a slight net loss.

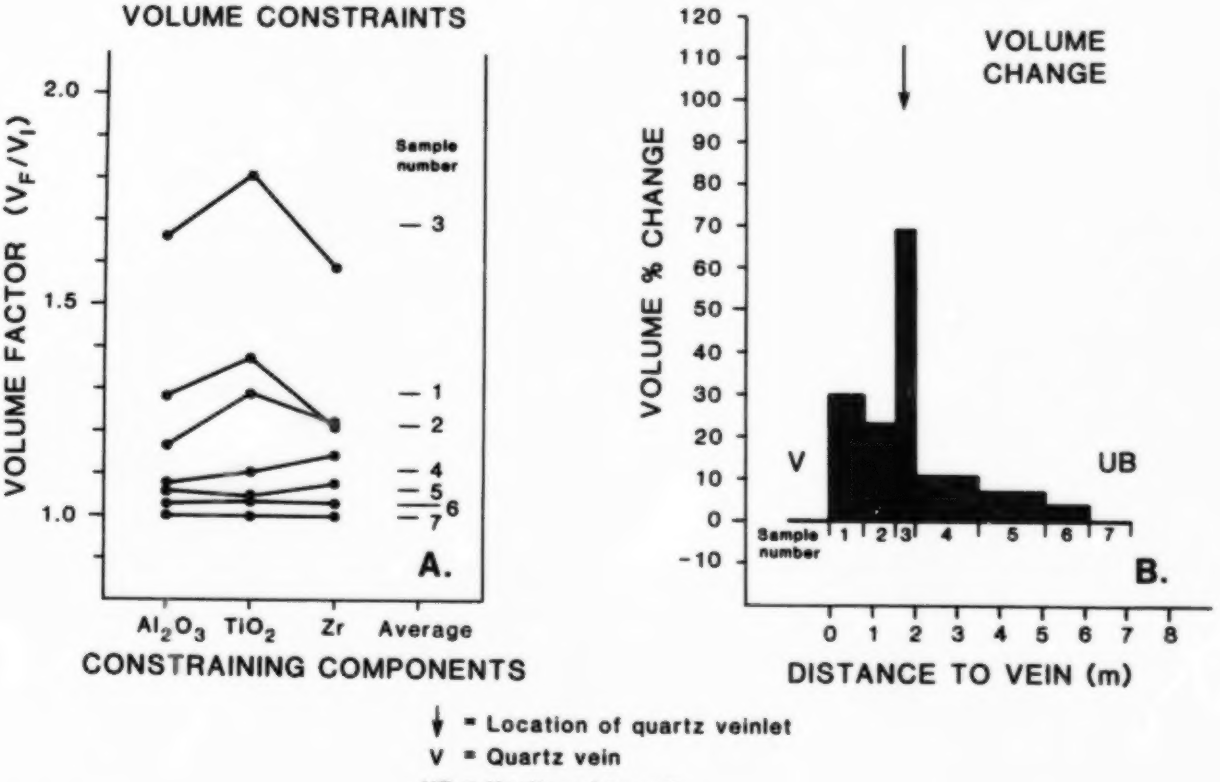

Figure 6-7-2. A — Volume factors (V final/V initial) estimated for each of six carbonatized basalt samples (1-6) and one unaltered sample (7) for each of three relatively immobile components. Volume factors (ratios) are estimated by the ratios of weight percentages for immobile elements in unaltered to altered samples, that is, Wt initial/Wt final. B — Interpreted volume change accompanying alterations for seven contiguous samples extending outwards from adjacent to Jennie vein (1) to unaltered wallrock (7).

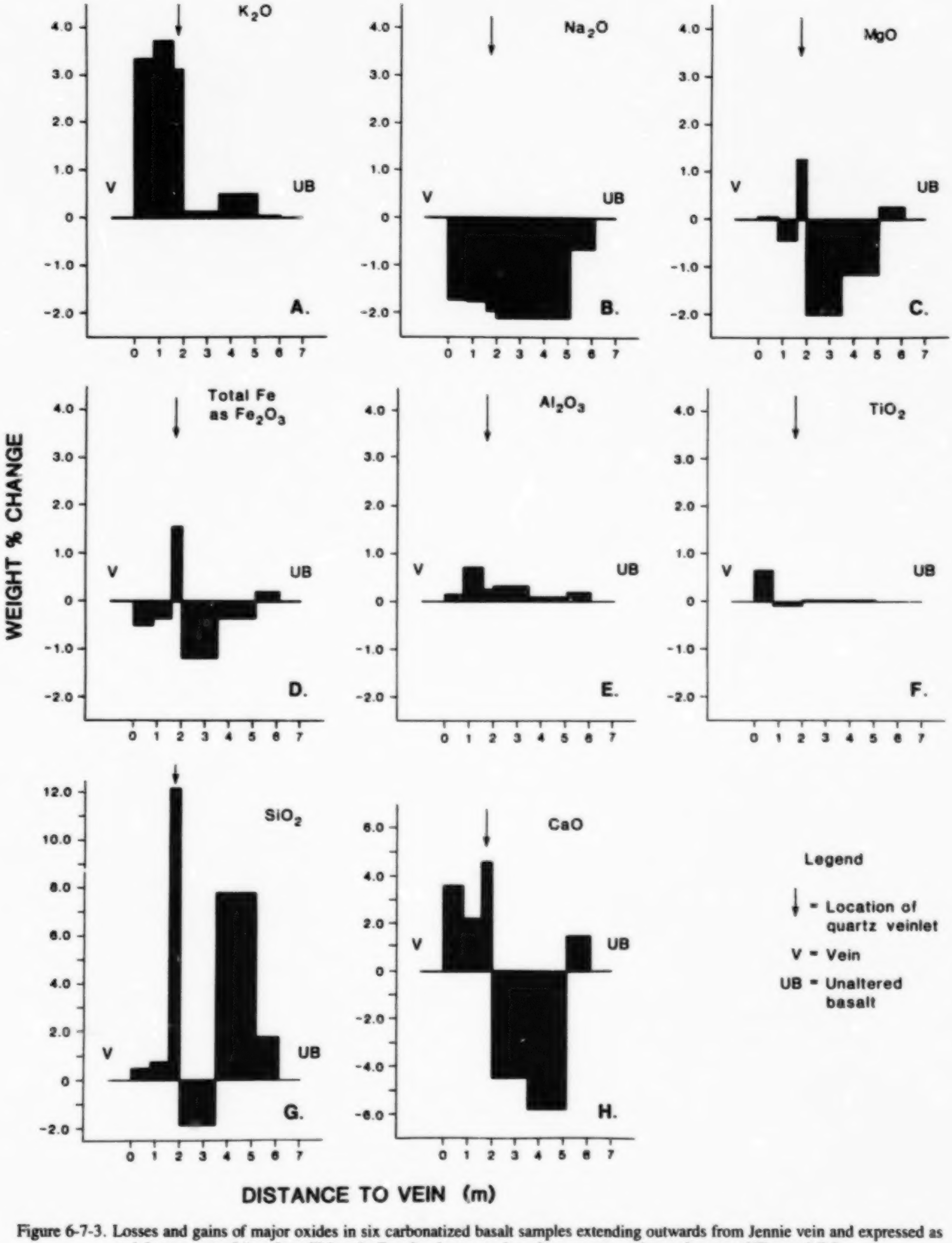

Figure 6-7-3. Losses and gains of major oxides in six carbonatized basalt samples extending outwards from Jennie vein and expressed as weight per cent of "unaltered" basalt. Results shown are based on average volume changes of Figure 6-7-2.

The nature of our chemical data did not permit identification of specific volatile materials such as H_2O, CO_2 and sulphur. Instead, we obtained a weight measure of "loss-on-ignition" (LOI) as shown in Figure 6-7-4 but recognize the addition of H_2O (sericite), CO_2 (carbonate) and S_2 (pyrite) to the alteration halo.

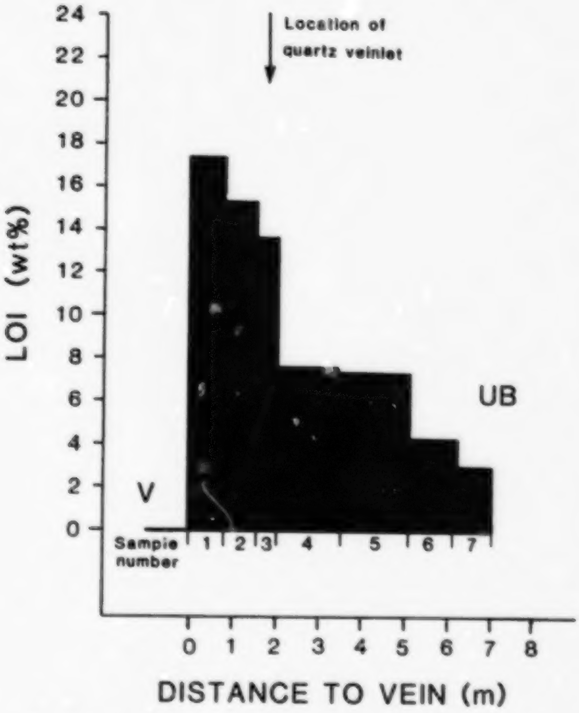

Figure 6-7-4. Loss-on-ignition (LOI) for seven contiguous basalt samples extending outwards from Jennie vein into unaltered basalt. Data from Table 6-7-1.

DISCUSSION

An understanding of element exchange during metasomatic processes involving wallrock alteration is an essential base for the interpretation of multi-element lithogeochemical data in precious metal exploration. For a quantitive study of the kind described here whole rock chemical analyses are required. It is important to realize that most multi-element inductively coupled plasma (ICP) data sets cannot be used for such calculations as they are generally obtained using partial extraction techniques. A small group of well-selected samples analysed both by ICP and an appropriate whole rock method (for example, X-ray fluorescence) will provide data to carry out the calculations recommended here and also will permit an evaluation of the extent of partial extraction inherent in the ICP data. Both types of information are essential to a sound interpretation of ICP data.

CONCLUSION

Gresens' metasomatic equation provides a useful procedure for examining gains and losses of elements in altered rocks. The procedure utilizes whole rock chemical analyses for altered and unaltered rocks and permits a quantitative evaluation of the effects of metasomatism without relying on peculiar constraints such as "constant number of oxygen atoms" or "constant number of silica tetrahedra".

In the case of the Jennie vein the whole rock data provide the following information:

(1) Volume changes during alteration are most pronounced near the vein (approximately 30 per cent) and decrease outwards toward unaltered wallrock.

(2) Addition of volatiles from the vein to altered wallrock decreases outwards from the vein wall.

(3) SiO_2 and K_2O have been added throughout the alteration halo with only rare exception.

(4) Na_2O, MgO and total Fe (as Fe_2O_3) have been lost from throughout the alteration halo.

(5) CaO has been redistributed in the alteration halo such that near the vein CaO is abnormally high whereas further away CaO has been lost.

(6) Al_2O_3 and TiO_2 appear to have increased slightly in the halo although these very minor changes may simply reflect local variations in the original composition.

ACKNOWLEDGMENTS

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CLASSIFICATION OF THE CRETACEOUS VOLCANIC SEQUENCES OF BRITISH COLUMBIA AND YUKON*

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INTRODUCTION

Cretaceous arc sequences of British Columbia and Yukon are of limited extent when compared to those of the Triassic-Jurassic period. They are mostly subalkaline but show such remarkable differences in their potash and soda contents that they seemed worthy of a detailed investigation.

Such investigation entails determining and describing magmatic trends, classifying the sequences, and comparing them to Recent suites. Three problems confronting the researcher at the start are: the confusing nomenclature expressing alkali and iron contents and trends; the absence of a classification of volcanic arcs which would reflect differences in potash content; and the difficulty of determining the original alkali and lime contents of altered sequences. In consequence, a discussion of proposed changes in nomenclature, of a new classification of arcs and suites, and of a method for screening "unaltered" data will introduce this study of the Cretaceous volcanic sequences. The revised nomenclature and screening method were developed earlier (de Rosen-Spence, 1976), but the new classification of arcs and suites proposed here is a direct outcome of the present study.

The volcanic suites for which data are available include sequences from the late Lower and Middle Cretaceous Gambier, Spences Bridge, Kingsvale, South Forks and Kasalka Groups, and the late Upper Cretaceous Mount Nansen, Hutshi and Carmacks Groups and Tip Top Hill Volcanics. This paper establishes that these sequences belong to different arc types, and to different series within these arc types; further, the suites can be compared to specific Recent suites. It is hoped that their precise classification will be useful for correlation purposes and that Recent analogs will enable reconstruction of the subduction environment in Cretaceous time.

REVISED NOMENCLATURE

ALKALI CONTENT

In his pioneering work, Kuno (1959, 1966) divided the Alkali versus SiO_2 diagram into "tholeiitic", "high-alumina" and "alkaline" domains according to the plot of the three main chains which form a full arc. It is proposed here to replace the terms "tholeiitic" and "high-alumina" by "calcic" and "calcalkaline" used with their strict chemical meaning (*see* Figure 6-8-6). This change is needed for three reasons:

(1) Standardization of nomenclature because arc tholeiitic suites are also the most calcic, with Peacock Indices of 67 to 64, and high-alumina suites are intermediate between calcic and alkaline, with Peacock Indices of 62 to 59;

(2) The domains so redefined can then also be used to describe non-arc tholeiitic suites with different alkali contents, such as the ridge tholeiitic suites of the Galapagos and Thingmuli. High-alumina arc basalts and non-arc medium-K tholeiites, which plot in the same calcalkaline domain, are well separated on the Al_2O_3 versus Alkali diagram (Kuno, 1960);

(3) Many authors are uneasy with the term "arc tholeiitic" for suites which are potassium-rich but plot in the arc tholeiitic domain, such as that of the West Carpathian arc.

IRON CONTENT

The iron-enrichment trend was originally named "tholeiitic" because it was first recognized in tholeiitic suites, whereas the trend lacking enrichment was described as "calcalkaline" because it seemed typical of the calcalkaline suite of the High Cascades and other similar continental arc sequences.

As new data on arc volcanism accumulated, it became obvious that arc volcanism was more varied than previously thought. Kuno (1950, 1959, 1966) showed that not only were there three parallel volcanic chains, composed of tholeiitic, high-alumina, and alkaline sequences, but also that so-called "tholeiitic" and "calcalkaline" trends could be found in any of the three suites, even within a single volcano. To avoid confusion, he redefined the Fe-rich and Fe-poor suites as "pigeonitic" and "hypersthenic" respectively on the basis of the groundmass pyroxene, and showed that they are well separated on the AFM diagram (Kuno, 1954; Aramaki, 1963). Now these terms are rarely used; most authors use the old terminology, with resulting confusion. It is therefore proposed that the terms "Fe-rich" and "Fe-poor" replace the older terms as being more descriptive of the iron-enrichment trend (de Rosen-Spence, 1976). Calcalkaline should be reserved for a specific alkali content as defined on the Alkali versus SiO_2 diagram, and tholeiitic used only for true tholeiites.

When dealing with altered sequences the AFM diagram becomes inaccurate because it is sensitive to any gain of alkali or magnesium. It is then preferable to use MgO versus FeO_T or FeO_T versus SiO_2 diagrams (de Rosen-Spence, 1976).

CLASSIFICATION OF SUITES AND ARCS

Potassium is an essential element in the classification of suites and arcs. It is now well documented that potassium increases across an island arc because it reflects depth to the Benioff zone (Sugimura, 1960; Kuno, 1966; Dickinson, 1968); however, arcs may differ from one another in their potash contents (Jakes and White, 1972).

Two diagrams are useful in evaluating the potassium content and classifying the diverse suites and arcs. These are: (1) the K_2O versus SiO_2 diagram of Gill (1981), modified to include basalts, rhyolites and alkaline potassic suites (Spence, 1985), and (2) the K_2O versus Na_2O (for 70 per cent SiO_2) diagram developed here.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

POTASH CONTENT WITHIN A SINGLE ARC

The low-K (LK), medium-K (MK) and high-K (HK) domains on the K_2O versus SiO_2 diagram (Figure 6-8-1) are used mainly to describe the potassium content of a suite, bearing in mind that actual trends may be steeper than the domain boundaries and that an additional sharp increase in K_2O may occur in the rhyolites. On this diagram, the three series of any single arc are well separated by sharp boundaries. In some cases, as in the Cascades, the calcalkaline series itself can be subdivided (Wise, 1969, page 1003) into a "true Cascades" type (Mount Hood) with a Peacock Index of 62, and a "high-alumina" type (Badger Butte, Newberry) with a Peacock Index of 60.5, perhaps on the verge of being alkaline. If, however, arcs with different potash contents are plotted on the same diagram, there is a marked overlap of the calcic, calcalkaline and alkaline series of the different arcs. This is well shown in Figure 6-8-1 by the three positions of the alkaline and calcic boundaries of the Cascades (I), Honsyu and Hokkaido (II) and West Carpathian and Eolian (III) arcs.

POTASH CONTENT OF ARCS AND THEIR CLASSIFICATION

The new diagram presented here is K_2O versus Na_2O for 70 per cent SiO_2 (Figure 6-8-2). It takes into account the antipathetic variation of sodium and potassium in suites which have the same total alkali content but different potash content (up to 1.5 per cent difference). It was designed for 70 per cent SiO_2 to offer a more open plot, although this has the disadvantage that K_2O must be projected on K_2O versus SiO_2 when dealing with less siliceous sequences. This diagram was constructed with data from Kuno (1962) Fiske *et al.* (1963), Karolus *et al.* (1968), Wise (1969), Gill (1970), Ewart *et al.* (1973), Higgins (1973), Barbieri *et al.* (1974) and Cantagrel *et al.* (1981). On it, arcs can be classified into three types, each containing calcic, calcalkaline and alkaline series:

Type I (more sodic): Izu, Fiji, Cascades,
Type II (moderately sodic): Tonga, Honsyu, Hokkaido,
Type III (less sodic): West Carpathian, Eolian arcs.

Among the calcic series, the low-K arc tholeiitic suites of Fiji and Izu Islands (Type I), and of Tonga (Type II) were deposited on thin oceanic crust, whereas the medium-K pre-Mount Hood dacites, Shasta and Hakone (Type I) and Honsyu-Hokkaido arc tholeiitic suites (Type II) were deposited on thicker crust. The unusual West Carpathian arc has the highest K_2O content of the calcic series, and is considered to be an intracontinental arc deposited on thick continental crust, possibly above subducted continental crust (Channel and Horvath, 1976).

CLASSIFICATION OF RECENT SUITES

Table 6-8-1 illustrates how Recent suites are classified according to their total alkali, potash and iron contents using Alkali versus SiO_2, K_2O versus SiO_2, Na_2O versus K_2O for 70 per cent SiO_2 and AFM or FeO_T versus SiO_2 diagrams. When rhyolites are absent from the sequence plotted, Na_2O and K_2O values for 70 per cent SiO_2 were projected on Na_2O versus and K_2O versus SiO_2. Na_2O does not increase above 65 per cent SiO_2 whereas K_2O tends to increase more rapidly, and care must be taken that the projected values fall in the appropriate total alkali domain on Na_2O versus K_2O.

RETRIEVAL OF "UNALTERED" DATA FROM ALTERED SEQUENCES

Original magmatic trends in altered sequences generally can be determined by screening the data on certain diagrams in order to retrieve "unaltered" or "least altered" analyses.

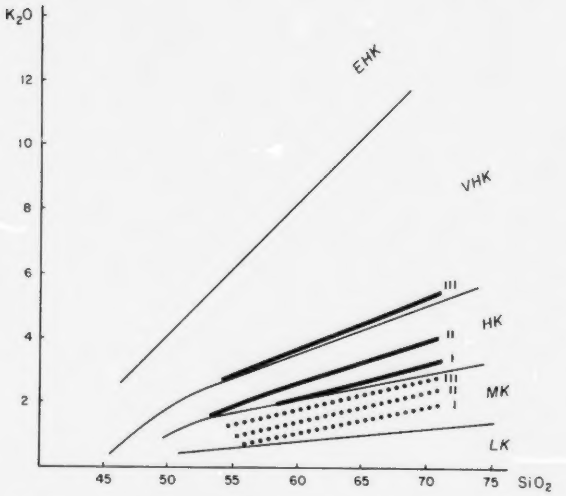

Figure 6-8-1. K_2O versus SiO_2 showing the calcic/calcalkaline (dotted lines) and calcalkaline/alkaline (heavy lines) boundaries for arcs with different K_2O contents: I = Fiji and Cascades (Shasta and Mount Hood); II = Honsyu and Hokkaido; III = West Carpathian and Eolian arcs [domains from Gill (1981) and Spence (1985)].

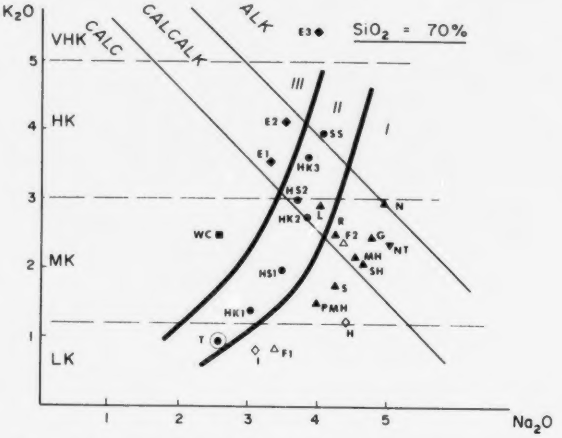

Figure 6-8-2. K_2O versus Na_2O for 70 per cent SiO_2 showing the distribution of Recent arcs and individual volcanoes into three types: I = Fiji-Izu-Cascades; II = Tonga-Honsyu-Hokkaido; III = West Carpathian-Eolian. (Type I: F1, 2 = Fiji arc; G = Garibaldi; H = Hakone (Izu Peninsula); I = Izu Islands; MH-= Mount Hood; MR = Mount Rainier; S = Mount Shasta; N = Newberry; NT = Novo de Toluca (Mexico); PMH = Pre-Mount Hood dacites. Type II: T = Tonga; HK1, 2, 3 = Hokkaido arc; HS1, 2 = Honsyu arc; SS = Sidara sheet (Honsyu). Type III: WC = West Carpathian arc; E1, 2, 3 = Eolian arc).

CaO LOSS

CaO is lost in many types of alteration unless it is trapped as calcite. Treatment of data on MgO versus CaO (Figure 6-8-3) separates a large number of altered samples. This diagram has the

TABLE 6-8-1.
CLASSIFICATION OF RECENT SUBALKALINE ARC SUITES

		TYPE I		TYPE II		TYPE III	
		Fe-poor	Fe-rich	Fe-poor	Fe-rich	Fe-poor	Fe-rich
MILDLY ALKALINE	VHK					Eolian.3	
	HK						
	HK/MK			Sidara Sheet			
	MK						
CALC-ALKALINE	HK					Eolian.2	
	HK			Hokkaido.3		Eolian.1	
	HK/MK	Newberry					
	MK	Mt. Hood		Honsyu.2			
	MK	St. Helens		Hokkaido.2			
	MK	Rainier		Lassen			
	MK	Fiji.2	Huzi		Talasea		
	LK						
CALCIC	HK						
	MK	Shasta					
	MK	Pre-Mt. Hood		Honsyu.1		West Carpathian	
	MK	Hakone		Hokkaido.1			
	LK		Izu	Tonga			
	LK		Fiji.1				

advantage of being valid for all volcanic suites, though lavas with plagioclase cumulates plot as enriched in calcium (de Rosen-Spence, 1976; Spence, 1985).

Na_2O GAIN OR LOSS

Plotting the screened "unaltered" data from Figure 6-8-3 on an Na_2O versus SiO_2 (Figure 6-8-4) allows the elimination of spilitized or sericitized samples where CaO was retained as calcite, as well as samples with marked K-Na exchanges. Such exchanges can be recognized by the antipathetic variation of potassium and sodium on Na_2O versus SiO_2 and K_2O versus SiO_2 (Figure 6-8-5) plots.

MgO GAIN

Rocks which have gained MgO also plot as "altered" and MgO gains can be assessed by plotting MgO versus SiO_2 (Spence, 1985, Figure 136). Care must be taken though, that there has been no silicification as this would also cause a shift of the data points into the magnesium-enriched field.

CRETACEOUS VOLCANISM OF BRITISH COLUMBIA AND YUKON

Two periods of Cretaceous volcanism have been recognized in the Canadian Cordillera by numerous workers and re-emphasized by Armstrong (1986, in press): one is in the late Lower and Middle Cretaceous, the other in latest Upper Cretaceous time. The first period is also one of vigorous plutonism and uplift, consequently much of the contemporaneous volcanic rock has been eroded. The event is subdivided into two episodes, Aptian (?) to Albian, and late Albian to Cenomanian, separated by the uplift of the Coast Plutonic Complex. Remnants of the once extensive submarine Albian Gambier Group are found in roof pendants of the southern Coast Plutonic Complex. In south-central British Columbia, the subaerial arc sequences of the late Albian Spences Bridge Group and Albian (?) "Kingsvale" Group near Aspen Grove occur east of the Fraser fault, those of Kingsvale Group of Chilko Lake form a thick sequence south of the Yalakom fault and are dated as Cenomanian. In the Bella Coola area, submarine and subaerial sequences may belong respectively to the Gambier and Kingsvale Groups. In central British Columbia, the shallow marine Albian volcanics of the Skeena Group and the later subaerial Cenomanian (?) Kasalka Group are but small remnants. In the Yukon, the unusual subaerial Albian South Forks Volcanics developed on the North American platform.

The second period, in Maastrichtian time (Grond *et al.*, 1984), is one of more subdued subaerial volcanism along a narrow belt which extends from Yukon to northern British Columbia; it is represented by the Mount Nansen, Carmacks and Hutshi Groups. In central British Columbia, the Tip Top Hill Volcanics mark the southern extension of this belt. Plutonism was also weak and only small plutons are found (Armstrong, 1986, in press).

GAMBIER GROUP

The Gambier Group is a submarine arc assemblage of basalts, andesites and dacite flows and tuffs with associated flysch and argillites. In the Harrison Lake area, there is evidence (Arthur, 1986) of episodes of Middle Triassic, Lower and Upper Jurassic and early Lower Cretaceous arc volcanism, all separated by unconformities. On Gambier Island, the Gambier Group rests unconformably on folded, intruded and eroded Triassic (?) greenstones of the Bowen Island Group and Late Jurassic diorite (Roddick, 1965). It is intruded by late Albian (?) and Cenomanian plutons (White, 1968). The existence of older arc sequences and intrusive rocks, together with reported Carboniferous zircon ages (Roddick *et al.*, 1979), indicates that the Gambier Group was deposited on a well-developed arc crust.

BRITANNIA MINE AREA

Data described following are from Margaret McColl (M.Sc. thesis, The University of British Columbia, in preparation). The Gambier Group in the mine area is altered (Figure 6-8-3), basalts are spilitized and dacitic flows and tuffs are mainly sericitized (Figures 6-8-4 and 6-8-5). Andesitic and dacitic dykes and some massive dacite samples plot as "unaltered" on MgO versus CaO (Figure 6-8-3) and give consistent magmatic trends. From these, the Britannia mine sequence can be defined as a medium-K (Figure 6-8-5), calcic (Figure 6-8-6) suite with a Peacock Index of 64; it is an **arc tholeiitic sequence.** It is Fe-poor, though close to the Fe-rich (tholeiitic) boundary, and belongs (Figure 6-8-7) to a Type I arc as defined previously. Heah *et al.* (1986) found that basalts of the nearby Sky Pilot area are also arc tholeiites showing Fe-rich and Fe-poor trends. The Gambier Group is close in composition to the Mount Shasta and Kuroko suites. The presence of older arc crust but deep marine conditions, together with volcanogenic deposits (Payne *et al.*, 1980), suggests an intra-arc extensional environment similar to that of the Green Tuffs-Kuroko trough in Japan (Sillitoe, 1982; Cathles *et al.*, 1983).

HARRISON LAKE AREA

On the west shore of Harrison Lake, the Gambier Group is represented by the Fire Lake Group and the Doctor's Point volcanics (Ray *et al.*, 1985). The Fire Lake Group is composed of altered andesites, whereas the Doctor's Point volcanics include dacites, and are relatively well preserved. The latter sequence plots as a low-K

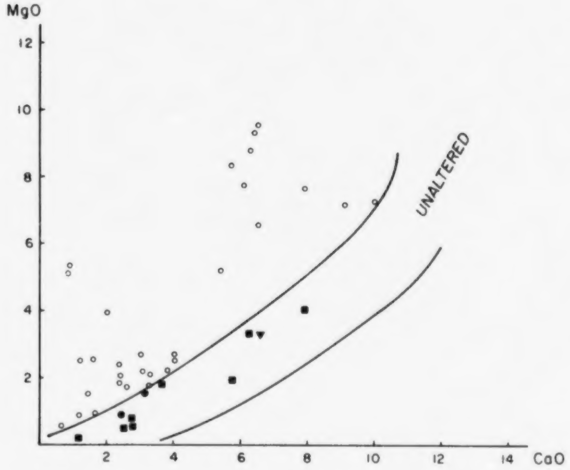

Figure 6-8-3. MgO versus CaO. Gambier Group, Britannia mine (circles = lavas; triangles = tuffs; squares = dykes in the mine; open symbols = altered; filled symbols = "unaltered"). Analyses from M. McColl (in preparation), domains from de Rosen-Spence (1976).

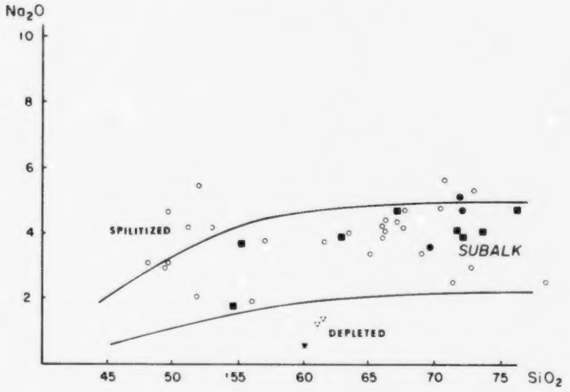

Figure 6-8-4. Na_2O versus SiO_2. Gambier Group, Britannia mine (notice the spilitized basalts and Na-depleted tuffs) (domains from de Rosen-Spence, 1976).

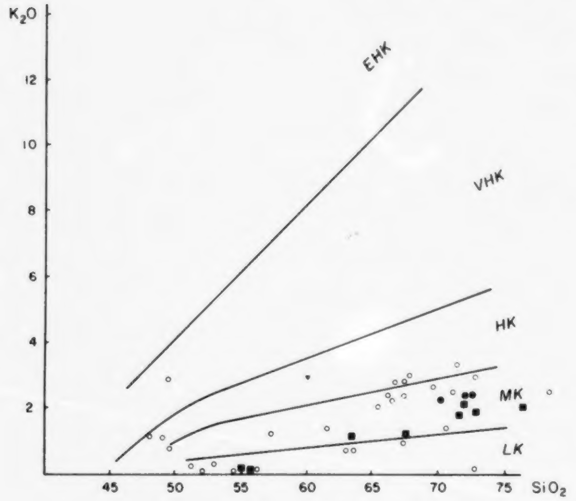

Figure 6-8-5. K_2O versus SiO_2. Gambier Group, Britannia mine (notice the well-defined trend of the "unaltered" dykes and the high K_2O content of the tuffs).

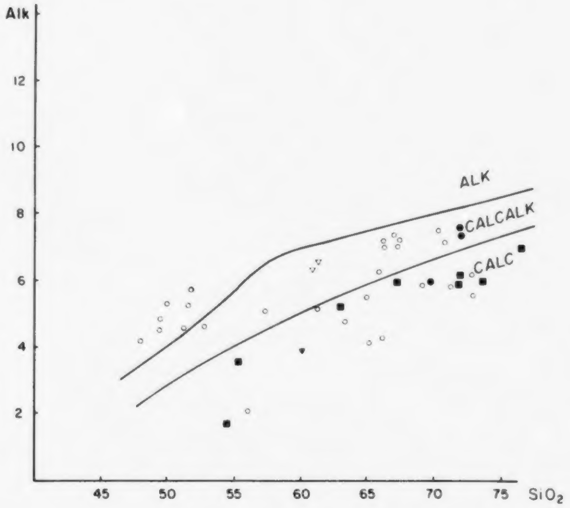

Figure 6-8-6. Alkali versus SiO_2. Gambier Group, Britannia mine (notice the well-defined trend of the "unaltered" dykes) (domains from Kuno, 1966).

(Figure 6-8-8), calcic (Figure 6-8-9) suite of Type I (Figure 6-8-7) similar to the Britannia sequence, though apparently less potassic. It is generally Fe-poor except for a few Fe-rich basalts (G.E. Ray, personal communication, 1986).

MOUNT RALEIGH PENDANT

The Mount Euridyce dacite is a low to medium (?)-K dacite of Type I (Woodsworth, 1979).

CALLAGHAN PENDANT

The andesites around the Northair mine are heavily altered. They are subalkaline and aluminous, and possibly — but not certainly — akin to those of the Britannia mine area (Miller, 1979).

SPENCES BRIDGE AND KINGSVALE GROUPS

The Spences Bridge and Kingsvale Groups were first defined east of the Fraser fault, where they form a 200-kilometre-long belt of differentiated subaerial volcanics resting unconformably over the Triassic and Jurassic volcanics of Stikinia. Both have recently been re-examined and analysed (Thorkelson, 1986) and redated by fossils to be of Late Albian age (Thorkelson and Rouse, in preparation). In the Kingsvale area, the two groups were found to be in stratigraphic continuity and similar in major element chemistry. As a result the Kingsvale Group has now lost its status as a group. Kingsvale andesites were renamed Spius Formation and integrated into the Spences Bridge Group. Near Aspen Grove, to the east, a small inlier of Lower Cretaceous volcanics was attributed to the Kingsvale Group by Preto (1979). Analyses from both sequences will be examined following. In the Chilko Lake area south of the Yalakom fault, other subaerial volcanics were also attributed to the Kingsvale Group but are reported to be unlike those east of the Fraser fault and have been dated as Cenomanian (Kleinspehn, 1985). No analyses are available.

SPENCES BRIDGE GROUP IN KINGSVALE AREA

Thorkelson (1986) showed that the Lower Spences Bridge Group and the Spius Formation, though similar in their major element compositions, differ in their titanium, phosphorus and trace element contents. The Spius andesites seem to have a plume component indicating the beginning of rifting of the Spences Bridge arc.

Plots of the Spences Bridge Group reveal that it is a medium-K (Figure 6-8-8), calcic (Figure 6-8-9) suite with a Peacock Index of 65 to 66; it is Fe-poor and belongs to a Type II arc (Figure 6-8-7) similar to the hypersthenic arc tholeiitic suite of Honsyu.

"KINGSVALE" GROUP OF ASPEN GROVE

Preto (1979) recognized two units, 10 and 11, in the Aspen Grove area and correlated them with the Kingsvale Group. Unit 10, containing andesites and rhyolites, was broadly dated as Albian and is intruded by a Cenomanian granite. Unit 11 is basaltic, is not dated, and is not in contact with Unit 10. Both units belong to a medium-K (Figure 6-8-10), calcalkaline (Figure 6-8-11) suite with a Peacock Index of 62. They are Fe-poor and belong to an arc transitional between Types I and II (Figure 6-8-7). Unit 11 however, is slightly richer in iron, titanium and phosphorus, suggesting a late or behind-the-arc setting. The Kingsvale sequence from Aspen Grove is therefore different in total alkali content from the Spences Bridge Group, including the Spius Formation, suggesting that it belongs to a different volcanic event.

SOUTH FORKS VOLCANICS

The South Forks volcanic rocks are a subaerial intracontinental arc sequence deposited on the North American platform and composed of differentiated flows and tuffs (Wood and Armstrong, 1982). These are described as potassic with a calcalkaline (Fe-poor) trend and are characterized by a high initial strontium ratio indicating a strong crustal influence. They have been dated as Albian and are intruded by a Cenomanian quartz monzonite (Wood and Armstrong, 1982).

The South Forks Volcanics plot as a high-K (Figure 6-8-12), calcic (Figure 6-8-8) suite with a Peacock Index of 66. They are very calcic and poor in sodium (Figure 6-8-9) in spite of their high potassium content and distinctly belong to an arc of Type III (Figure 6-8-7). The most comparable Recent suite is that of the intracontinental West Carpathian arc (Karolus *et al.*, 1968). The quartz monzonite, also of Type III, is calcalkaline, indicating an increase in alkali with time.

KASALKA GROUP

MacIntyre (1976) showed that the andesites and rhyolites of the Kasalka Group were preserved in a cauldron subsidence complex. They were deposited subaerially, in early Late Cretaceous time, over a folded and eroded sequence of the shallow marine Skeena Group of Albian age. The sequence was intruded by the Mount Bolum granophyres and the varied plutons of the Bulkley suite. The latter was dated as latest Upper Cretaceous (Carter, 1982), contemporaneous with the next volcanic period.

The Kasalka Group data plot along the medium-K to high-K boundary (Figure 6-8-13), calcalkaline (Figure 6-8-14) and Fe-poor, and belonging to a Type II, near Type I arc (Figure 6-8-7), similar to the Kingsvale Group of Aspen Grove. The Mount Bolum granophyres are at the alkaline limit whereas the Bulkley intrusions are calcalkaline and less sodic (Figure 6-8-7).

MOUNT NANSEN GROUP AND TIP TOP HILL VOLCANICS

Data presented are from Grond *et al.* (1984) for the Mount Nansen Group in Yukon and from Church (1970) for one analysis of the Tip Top Hill Volcanics in central British Columbia. This subaerial volcanism is similar to that of the Kasalka Group (Figures 6-8-13, 6-8-14 and 6-8-7). The Montana Mountain sequence, which belongs to the Hutshi Group (Roots, 1982), is also similar but very altered.

CARMACKS GROUP

Data presented are from Grond *et al.* (1984). The Carmacks Group overlies the Mount Nansen Group and has the same radiometric age. It is composed of shoshonite flows and of breccias including calcalkaline andesite clasts (Figures 6-8-13 and 6-8-14). This shoshonitic volcanism is important as it indicates disturbance through collision of the Maastrichtrian subduction zone.

CONCLUSION

The methods presented here for screening altered samples and classifying volcanic suites have allowed more accurate definition and comparison of Cretaceous volcanic sequences with more recent suites. It is hoped that this may eventually lead to a more accurate reconstruction of the old subduction zones and arc margins.

The main results of interest are:

(1) Identification of the Gambier Group as an arc tholeiitic suite of Type I, similar to other arc sequences hosting copper-zinc massive sulphides, such as the Miocene Kuroko and Archean Noranda sequences;

(2) Identification of the Spences Bridge Group and South Forks Volcanics — previously described as "calcalkaline" — as calcic suites (Peacock Index of 66) with high potash and cor-

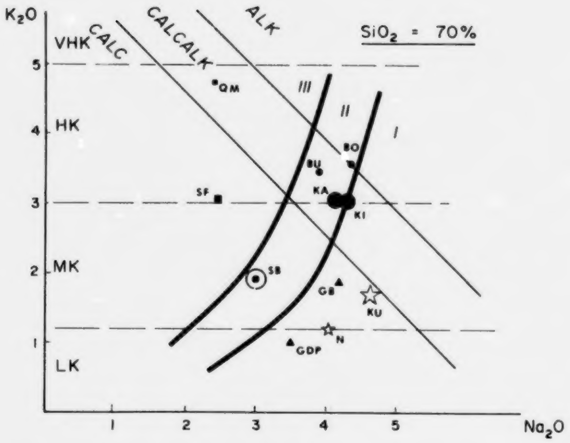

Figure 6-8-7. K_2O versus Na_2O for 70% SiO_2, showing the distribution of the Cretaceous arcs into three types: I = Gambier Group (GDP = Doctor's Point; GB = Britannia mine) and Noranda (N) and Kuroko (K) dacites for comparison; II = Spences Bridge (SB), "Kingsvale" of Aspen Grove (KI), Kasalka and Mount Nansen (KA) Groups and Mount Bolum (BO) and Bulkley (BU) intrusions; III = South Forks Volcanics (SF) and Quartz Monzonite (QM).

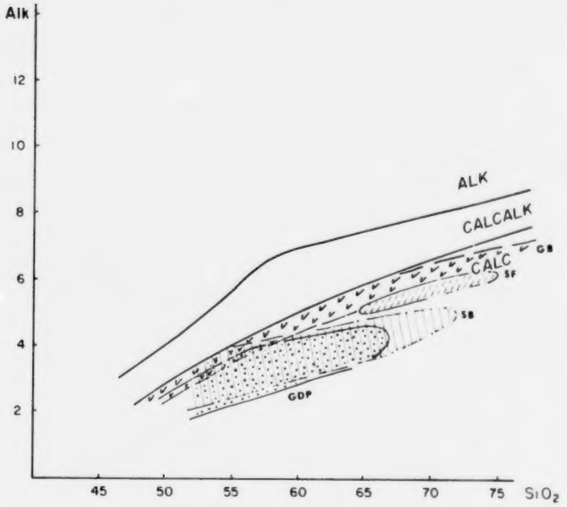

Figure 6-8-8. Alkali versus SiO_2 for the Gambier and Spences Bridge Groups and South Forks Volcanics. Legend as in Figure 6-8-12.

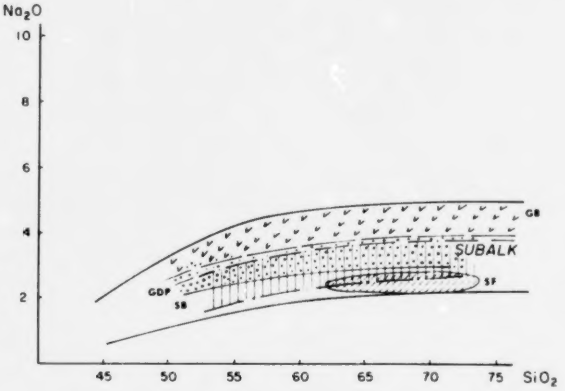

Figure 6-8-9. Na_2O versus SiO_2 for the Gambier and Spences Bridge Groups and South Forks Volcanics. Legend as in Figure 6-8-12.

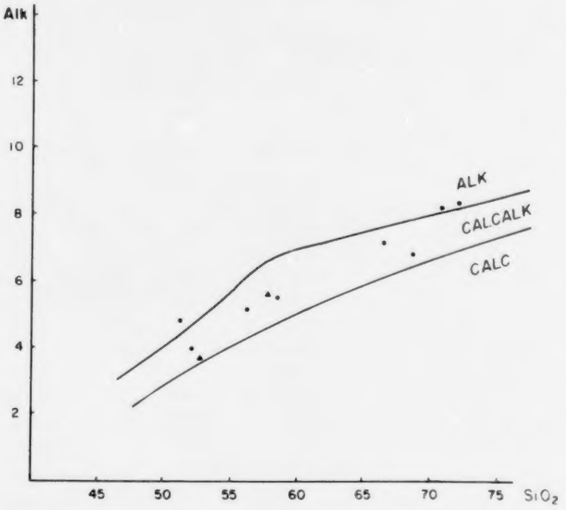

Figure 6-8-10. Alkali versus SiO_2 for the "Kingsvale" Group of Aspen Grove (Unit 10 = circles; Unit 11 = triangles). Analyses from Preto (1979).

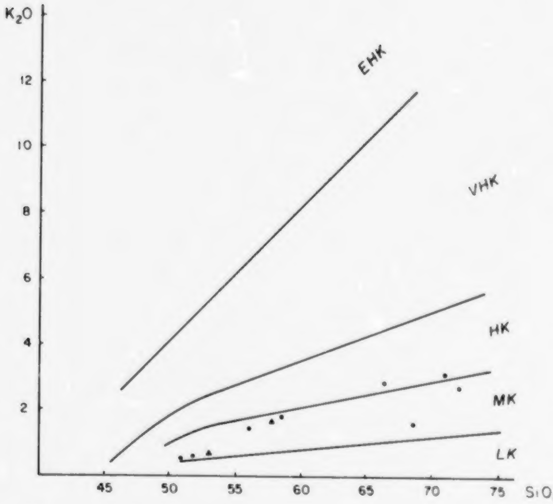

Figure 6-8-11. K_2O versus SiO_2 for the "Kingsvale" Group of Aspen Grove (Unit 10 = circles; Unit 11 = triangles).

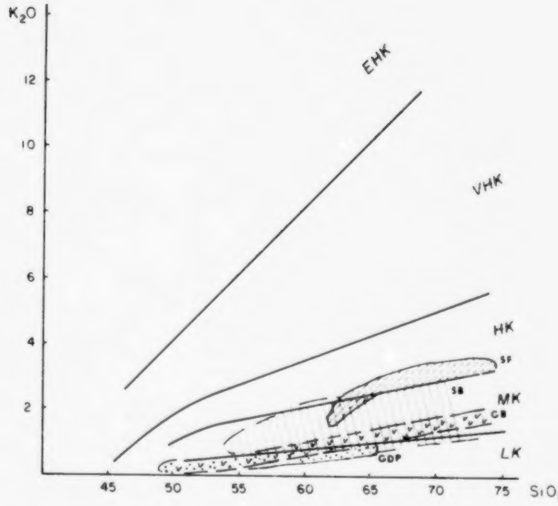

Figure 6-8-12. K_2O versus SiO_2 for the Gambier Group in Doctor's Point areas (dots), and Britannia mine area (VVV), Spences Bridge Group (lines) and South Forks Volcanics (dashes). Analyses from Ray (personal communication), McColl (in preparation), Thorkelson (1986) and Wood and Armstrong (1982).

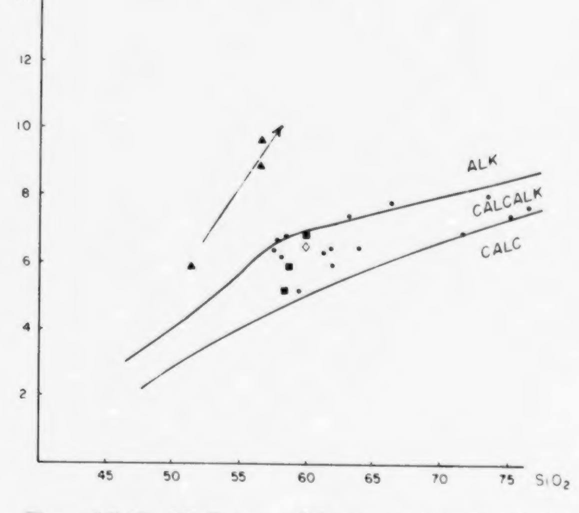

Figure 6-8-13. Alkali versus SiO_2 for the Kasalka (circles), Mount Nansen (squares), Tip Top Hill (diamond) and Carmacks (triangles) Groups. Analyses from Church (1970), MacIntyre (1976) and Grond *et al.* (1984).

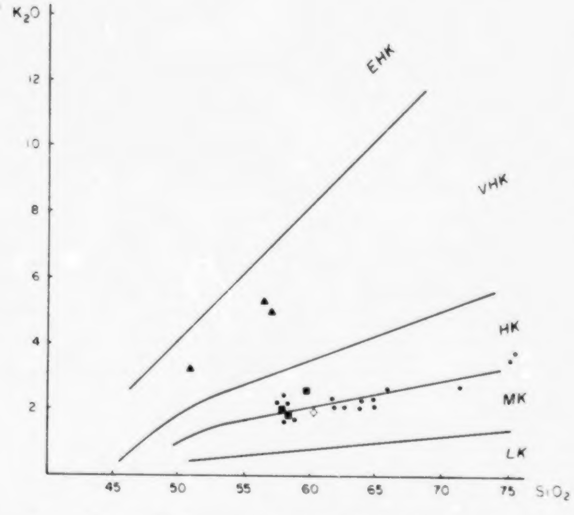

Figure 6-8-14. K_2O versus SiO_2 for the Kasalka, Mount Nansen, Tip Top Hill and Carmacks Groups. Legend as in Figure 6-8-13.

relatively low soda contents, and their comparison to the Honsyu arc tholeiites and West Carpathian arc respectively;

(3) Differentiation of Spences Bridge Group and Kingsvale volcanic rocks from the Aspen Grove area, which precludes their correlation;

(4) Identification of important differences between the Gambier and Spences Bridge Groups indicating that they belong to two different episodes or to two different arc segments. Similar differences are found between the Miocene Green Tuffs-Kuroko rhyolites and the present Honsyu arc in the same area, or between the Recent Izu and Honsyu arcs. This difference in composition is thought to result from differences in the conditions of subduction in time and/or location;

(5) Recognition that there is a need for data from the Cretaceous sequences of the Chilko Lake and Bella Coola areas.

ACKNOWLEDGMENTS

This paper represents a small part of a study of whole rock chemical data for volcanic sequences in British Columbia undertaken at The University of British Columbia, and funded by the Science Secretariat of British Columbia and the British Columbia Ministry of Energy, Mines and Petroleum Resources through the Canada/British Columbia Mineral Development Agreement. We wish to thank M. McColl, G. Ray and D. Thorkelson for their unpublished analyses and Dr. R.L. Armstrong for discussions on Cretaceous volcanism.

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Data Systems

COALFILE

By Candace E. Kenyon

BACKGROUND

The Geological Survey Branch maintains a large library of coal assessment reports, dating from 1900, submitted by exploration companies in compliance with the *Coal Act*. Exploration data from the assessment reports have been summarized and stored in a computer information system called COALFILE, to provide a quick and efficient method for handling the large volume of data. Refer to Geological Fieldwork, 1984 (Paper 1985-1, page 339) and 1985 (Paper 1986-1, page 235) for the history of the project. Information in COALFILE is useful in exploration planning and it provides a resource base for federal and provincial government agencies, and universities. Updating and maintenance of this file are an ongoing project.

PROJECT STATUS

For details concerning the computer specifications and the type of data residing in COALFILE, refer to Geological Fieldwork, 1985 (Paper 1986-1, page 236).

This year, information was extracted from the 1985 coal assessment reports received by the Ministry and appended to COALFILE. The hardcopy files were recatalogued and a new numbering system was implemented. These unique numbers reside in the computer for easy reference. Table 7-1-1 provides a summary of the number of records in the database for each file type.

TABLE 7-1-1.
SUMMARY OF RECORDS STORED IN COALFILE

RECORD TYPE	TOTAL NUMBER OF RECORDS
Explore	682
Comment	467
Map	596
Trench	3122
Bulk	430
Borehole	6720

INFORMATION AVAILABLE

The type of output available from COALFILE is outlined in Geological Fieldwork, 1985 (Paper 1986-1, page 236). A detailed order form with associated costs for data requests is available in brochure form from the Ministry (COALFILE, Information Circular 1986-1).

There is a three-year confidential period for coal exploration assessment reports; only nonconfidential information is available to the public.

For further information, please contact Candace Kenyon at (604) 387-1301; mailing address: Ministry of Energy, Mines and Petroleum Resources, Mineral Resources Division, District Geology and Coal Resources, Parliament Buildings, Victoria, British Columbia V8V 1X4.

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MINFILE-REDESIGN AND PROGRESS REPORT*

By A. F. Wilcox and C. B. Borsholm

INTRODUCTION

Important progress has been made in the redesign of MINFILE during the past year. An "ideal" database model (Figure 7-2-1) was drafted for database navigation, several new coding forms (Figures 7-2-2 and 7-2-3) and a new coding manual were completed, and all existing data that resided on the IBM mainframe were downloaded into the VAX in the new format. In addition, under the Canada/British Columbia Mineral Development Agreement (MDA), recoding of all mineral occurrences in MINFILE began. Two open file publications were also prepared, one on platinum and one on magnesite occurrences (in press) in the province.

DATABASE DESIGN

"A 'mineral deposit' includes naturally occurring deposits of both metallic and industrial minerals and of the fossil fuels and is defined as a volume of mineral-bearing material of economic or scientific interest sufficiently homogeneous in the opinion of the file-builder to be considered an entity" (Geological Survey of Canada, Paper 78-26).

This definition is used to form the basis of MINFILE occurrences. When the redesign of MINFILE commenced it was decided to use a relational database model and techniques for the database design.

The ideal design of the database, in terms of an "entity-relationship" model, is illustrated in Figure 7-2-1. The square boxes represent entities, diamond-shaped boxes show the relationship of the entity to mineral deposits and circles represent attributes of the entity. The way the "entity-relationship" model works is illustrated by the following example; a deposit type may contain many mineral deposits and a mineral deposit may be characterized as more than one deposit type, for example, "vein" and "stockwork".

Attributes can be generally thought of as deposit type codes and descriptions of all the tables that make up the relational database.

COMPUTER SOFTWARE

CINCOM Systems is the vendor of our computer software. The main product, called ULTRA, is a directory driven database and information management system designed for the VAX minicomputer using the VMS operating system.

The ULTRA directory is the central point of control for the system. Its integration with Logical User Views (LUV) insulates all users from the physical structure of the database. A subsequent change to a logical view usually does not require programs to be changed or recompiled.

ULTRA allows standard application programs written in COBOL, FORTRAN, or BASIC to access the database management system (DBMS) without including logic to physically navigate the DBMS. The programmer simply accesses the logical view of the data needed. MANTIS, another CINCOM product, is a fourth generation language that is able to interact directly with the LUV and DBMS.

The new MINFILE programs were written in MANTIS with the exception of a routine to convert latitude/longitude to UTM which is written in FORTRAN. After initial testing of the report outputs it was found that MANTIS could not easily produce the type of output reports required. It was decided that COBOL was the most logical alternative.

DATA COLLECTION

CODING FORMS

During the past 18 months the coding form has undergone five revisions, with the latest version illustrated in Figure 7-2-2. Production and reserve information is input from separate coding forms (*see* detail on reserves following). The information indicated by the dashed lines on the main coding form represents information that is collected for the geologists (coders) use only and is not stored in the computer.

NEW FIELDS

The reader is referred to the MINFILE coding manual (in press) for detailed decriptions of fields, codes and tables. Below is a brief summary of the significant changes.

STATUS

When a property has reached the development stage and beyond, extensive work has usually been performed, often including bulk sampling or production. It is now possible to record whether this work has been conducted on surface or underground.

MINERALIZATION

We are now gathering information on gangue and alteration minerals as well as information on the economic mineralization. The age of the mineralization and isotopic dating of the deposit are also recorded.

GEOMETRY

Information is now being gathered on the geometry of the mineral deposit. This information includes shape of the deposit (for example, tabular), modifiers to the shape (for example, faulted), the dimensions of the deposit and the attitude.

HOST ROCK

The host rock section of the coding form is divided into three sections: dominant rock type; stratigraphy; and igneous/metamorphic/other relationships. Data are also gathered on the age of the host rock.

GEOLOGICAL SETTING

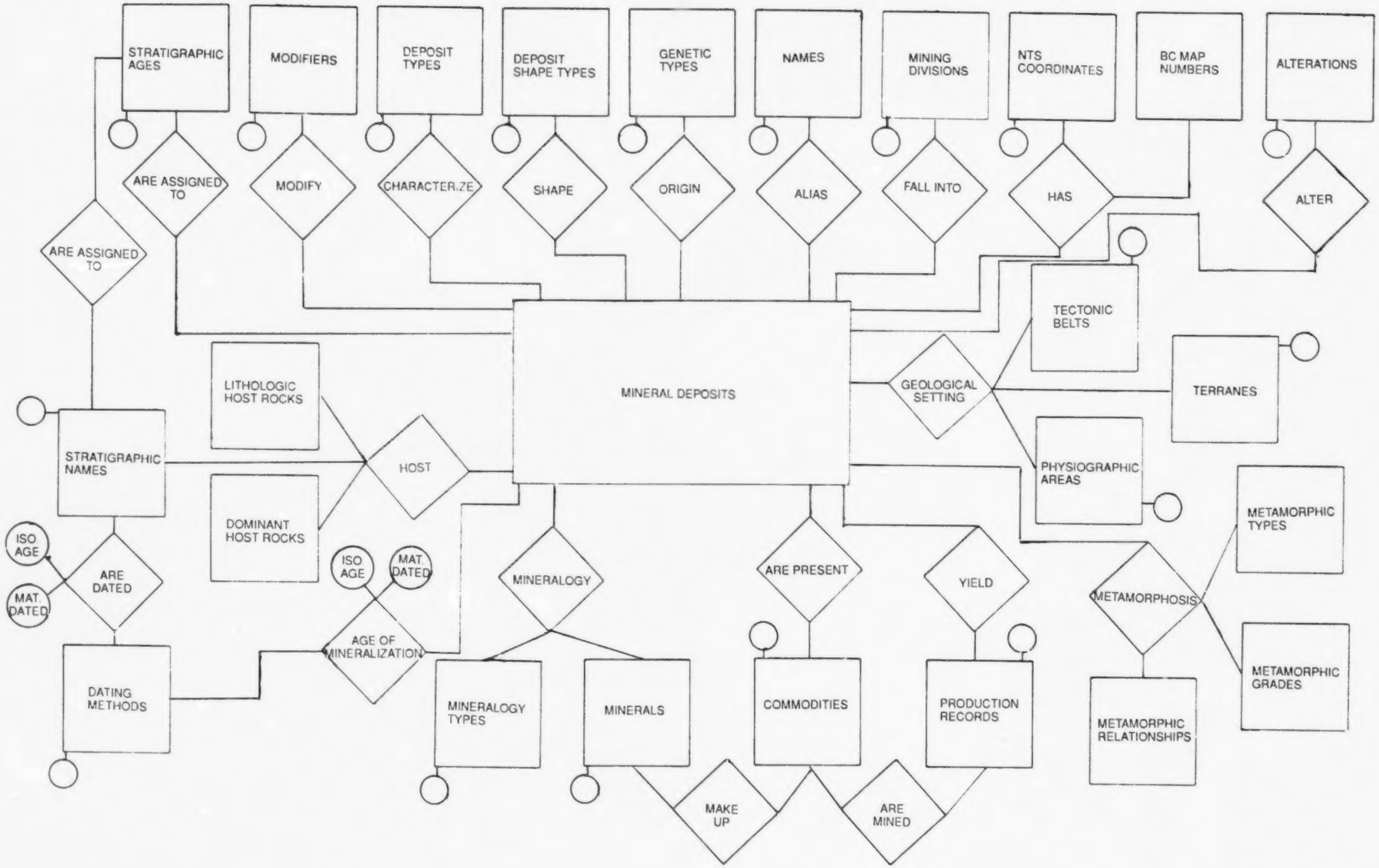
Information on the geological setting of the mineral occurrence is now gathered and stored. This includes the tectonic belt that the mineral occurrence resides in, the terrane associated with the occurrence, the physiographic region and any available data on metamorphic relationships and grades.

TEXT

One of the strong features of the system is the ability to input an unlimited amount of textual information.

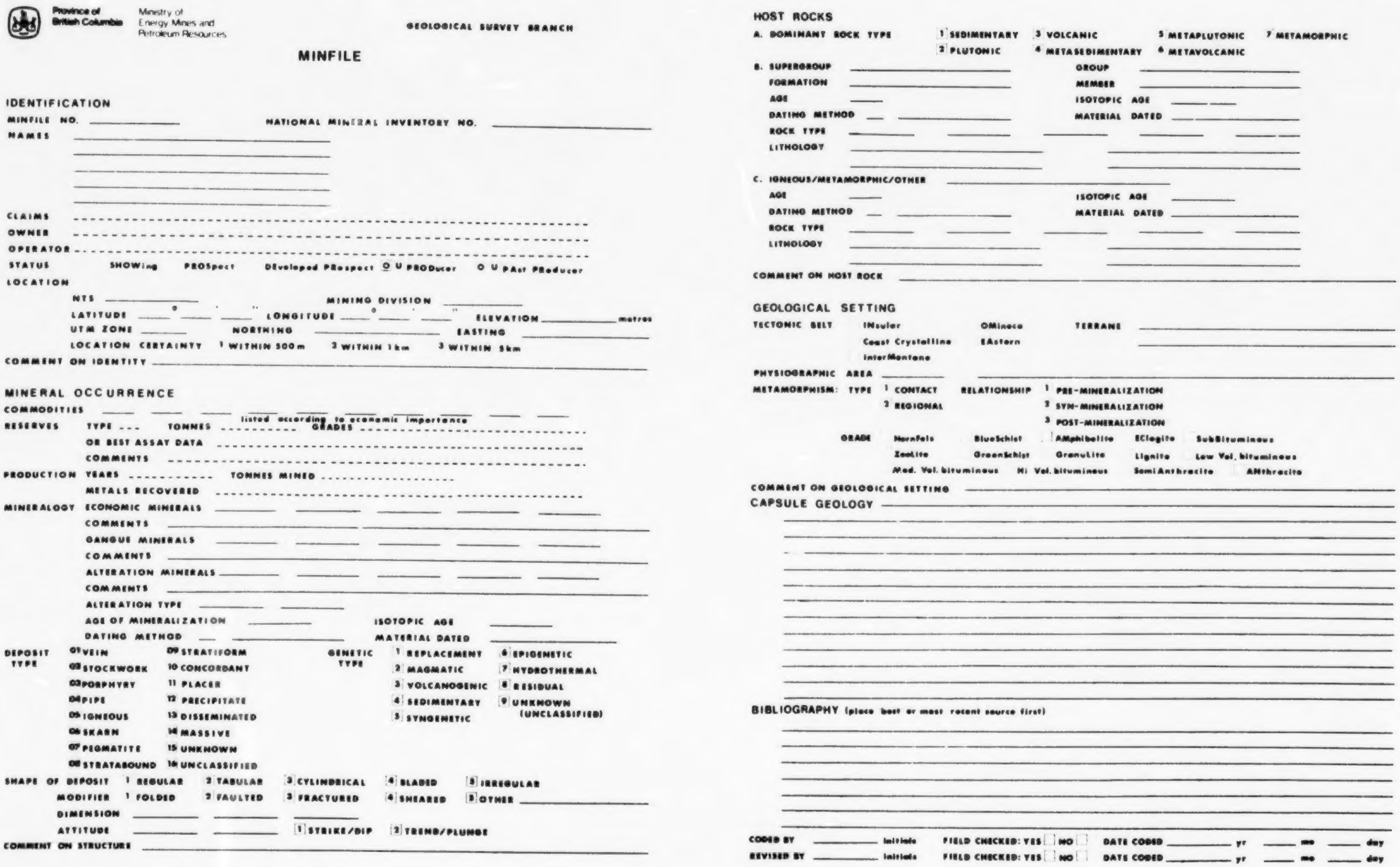
---

* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.


ENTITY - RELATIONSHIP MODEL: "IDEAL"

STRATIGRAPHIC AGES
MODIFIERS
DEPOSIT TYPES
DEPOSIT SHAPE TYPES
GENETIC TYPES
NAMES
MINING DIVISIONS
NTS COORDINATES
BC MAP NUMBERS
ALTERATIONS
ARE ASSIGNED TO
MODIFY
CHARACTERIZE
SHAPE
ORIGIN
ALIAS
FALL INTO
HAS
ALTER
ARE ASSIGNED TO
TECTONIC BELTS
LITHOLOGIC HOST ROCKS
MINERAL DEPOSITS
GEOLOGICAL SETTING
TERRANES
STRATIGRAPHIC NAMES
HOST
PHYSIOGRAPHIC AREAS
DOMINANT HOST ROCKS
METAMORPHIC TYPES
ISO. AGE
ARE DATED
MAT. DATED
ISO. AGE
MAT. DATED
MINERALOGY
ARE PRESENT
YIELD
METAMORPHOSIS
AGE OF MINERALIZATION
DATING METHODS
MINERALOGY TYPES
MINERALS
COMMODITIES
PRODUCTION RECORDS
METAMORPHIC RELATIONSHIPS
METAMORPHIC GRADES
MAKE UP
ARE MINED

Figure 7-2-1. Entity-Relationship Model: "Ideal".



Province of British Columbia
Ministry of Energy Mines and Petroleum Resources

GEOLOGICAL SURVEY BRANCH

MINFILE

IDENTIFICATION

MINFILE NO. ______ NATIONAL MINERAL INVENTORY NO. ______

NAMES ______

CLAIMS ------

OWNER ------

OPERATOR ------

STATUS SHOWing PROSpect DEveloped PRospect O U PRODucer O U PAst PReducer

LOCATION

NTS ______ MINING DIVISION ______

LATITUDE ___° ___' ___" LONGITUDE ___° ___' ___" ELEVATION ______ metres

UTM ZONE ______ NORTHING ______ EASTING ______

LOCATION CERTAINTY 1 WITHIN 500 m 2 WITHIN 1 km 3 WITHIN 5 km

COMMENT ON IDENTITY ______

MINERAL OCCURRENCE

COMMODITIES ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ listed according to economic importance

RESERVES TYPE --- TONNES ------ GRADES ------

OR BEST ASSAY DATA ------

COMMENTS ------

PRODUCTION YEARS ------ TONNES MINED ------

METALS RECOVERED ------

MINERALOGY ECONOMIC MINERALS ___ ___ ___ ___ ___

COMMENTS ______

GANGUE MINERALS ___ ___ ___ ___ ___

COMMENTS ______

ALTERATION MINERALS ___ ___ ___ ___ ___

COMMENTS ______

ALTERATION TYPE ___ ___

AGE OF MINERALIZATION ______ ISOTOPIC AGE ______

DATING METHOD ___ ______ MATERIAL DATED ______

DEPOSIT TYPE

- 01 VEIN
- 02 STOCKWORK
- 03 PORPHYRY
- 04 PIPE
- 05 IGNEOUS
- 06 SKARN
- 07 PEGMATITE
- 08 STRATABOUND
- 09 STRATIFORM
- 10 CONCORDANT
- 11 PLACER
- 12 PRECIPITATE
- 13 DISSEMINATED
- 14 MASSIVE
- 15 UNKNOWN
- 16 UNCLASSIFIED

GENETIC TYPE

- 1 REPLACEMENT
- 2 MAGMATIC
- 3 VOLCANOGENIC
- 4 SEDIMENTARY
- 5 SYNGENETIC
- 6 EPIGENETIC
- 7 HYDROTHERMAL
- 8 RESIDUAL
- 9 UNKNOWN (UNCLASSIFIED)

SHAPE OF DEPOSIT 1 REGULAR 2 TABULAR 3 CYLINDRICAL 4 BLADED 5 IRREGULAR

MODIFIER 1 FOLDED 2 FAULTED 3 FRACTURED 4 SHEARED 5 OTHER ______

DIMENSION ___ ___ ___

ATTITUDE ___ ___ 1 STRIKE/DIP 2 TREND/PLUNGE

COMMENT ON STRUCTURE ______

HOST ROCKS

A. DOMINANT ROCK TYPE 1 SEDIMENTARY 2 PLUTONIC 3 VOLCANIC 4 METASEDIMENTARY 5 METAPLUTONIC 6 METAVOLCANIC 7 METAMORPHIC

B. SUPERGROUP ______ GROUP ______

FORMATION ______ MEMBER ______

AGE ___ ISOTOPIC AGE ___

DATING METHOD ___ ______ MATERIAL DATED ______

ROCK TYPE ___ ___ ___ ___ ___

LITHOLOGY ______

C. IGNEOUS/METAMORPHIC/OTHER ______

AGE ___ ISOTOPIC AGE ___

DATING METHOD ___ ______ MATERIAL DATED ______

ROCK TYPE ___ ___ ___ ___ ___

LITHOLOGY ______

COMMENT ON HOST ROCK ______

GEOLOGICAL SETTING

TECTONIC BELT INsular Coast Crystalline InterMontane OMineca EAstern TERRANE ______

PHYSIOGRAPHIC AREA ______

METAMORPHISM: TYPE 1 CONTACT 2 REGIONAL RELATIONSHIP 1 PRE-MINERALIZATION 2 SYN-MINERALIZATION 3 POST-MINERALIZATION

GRADE Hornfels ZeoLite Med. Vol. bituminous BlueSchist GreenSchist Hi Vol. bituminous AMphibolite GranuLite EClogite Lignite SemiAnthracite SubBituminous Low Vol. bituminous ANthracite

COMMENT ON GEOLOGICAL SETTING ______

CAPSULE GEOLOGY ______

BIBLIOGRAPHY (place best or most recent source first)

CODED BY ______ initials FIELD CHECKED: YES ☐ NO ☐ DATE CODED ______ yr ___ mo ___ day

REVISED BY ______ initials FIELD CHECKED: YES ☐ NO ☐ DATE CODED ______ yr ___ mo ___ day

Figure 7-2-2. Coding form.

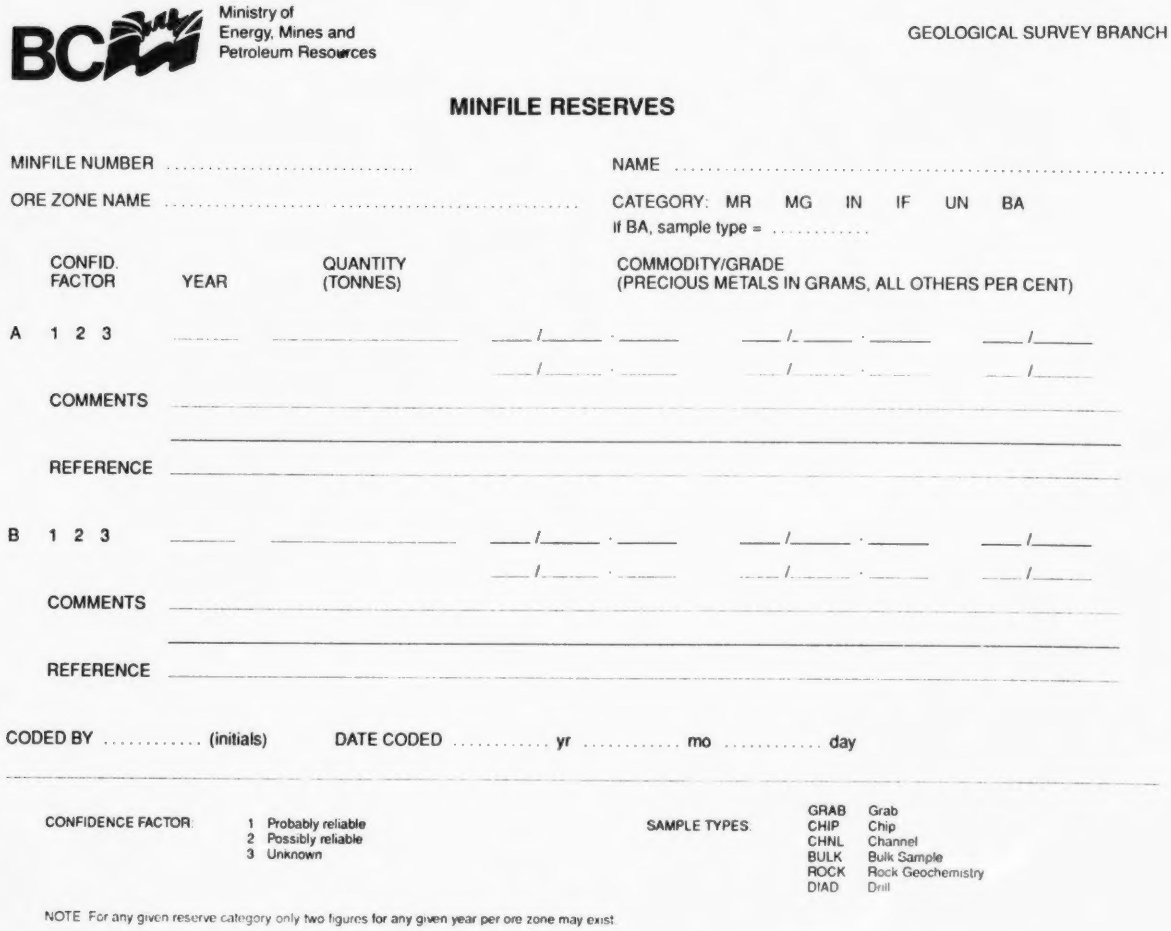
RESERVES

A new reserves coding form has been designed (*see* Figure 7-2-3) and has seen limited distribution. In the previous versions of MINFILE all reserve calculations for a property were saved no matter how many or what the status of the reserves were. Under the new design only two reserve figures for a given year per ore zone may be entered for any single reserve category. Only the most recent year in each category will be saved. A new category called "Best Assay" has been added with its associated sampling method being noted. The best assay category is for significant properties which have not had enough development work completed on them for formal reserve figures to be calculated. After formal reserve figures for the property have been released the best assay category will be deleted from core storage for that mineral occurrence. Another new feature which has just been introduced is a confidence factor. This is meant to give the end-users of MINFILE an indication of the reliability of the reserve measurements. No reflection is intended on who calculated the reserve figures, but is strictly a judgment value assigned by the coder, based on reliability of information. For example, data from a feasibility study are assigned a higher reliability than information from a press release.

DATA RETRIEVAL

Two methods exist for data retrieval. SPECTRA, a CINCOM product which can be used for conducting *ad hoc* enquries on any field in the database, and through the use of preprogrammed searches. Only the preprogrammed searches will be dealt with here. The enquiry system is based on the use of Boolean logic to search and reduce the resultant deposit file. This involves the use of "and", "or" and "not" conditions to reduce a file. For example, if a list is requested for deposits containing gold "and" silver, then all deposits that contain both commodities will be shown. If a list is requested for deposits containing gold 'or' silver, then all deposits containing one or the other commodity will be returned.

The enquiry process begins when the area selection screen is returned. The user initially has the option of narrowing the search by choosing an area either by latitude/longitude; UTM; or NTS designations. This can be further used in conjunction with either mining divisions, physiographic regions, tectonic belts or terranes. The default is the whole province. When a result is obtained a new menu appears listing the twelve preprogrammed searches (Table 7-2-1). At any stage of the search the user has the option of browsing any



BC Ministry of
Energy, Mines and
Petroleum Resources

GEOLOGICAL SURVEY BRANCH

MINFILE RESERVES

MINFILE NUMBER ....

NAME ....

ORE ZONE NAME ....

CATEGORY: MR MG IN IF UN BA

If BA, sample type = ...

CONFID. FACTOR	YEAR	QUANTITY (TONNES)	COMMODITY/GRADE (PRECIOUS METALS IN GRAMS, ALL OTHERS PER CENT)	
A 1 2 3	______	____________	___/___ · ___ ___/___ · ___ ___/___	
			___/___ · ___ ___/___ · ___ ___/___	

COMMENTS ____

____

REFERENCE ____

B 1 2 3	______	____________	___/___ · ___ ___/___ · ___ ___/___	
			___/___ · ___ ___/___ · ___ ___/___	

COMMENTS ____

____

REFERENCE ____

CODED BY .... (initials) DATE CODED .... yr .... mo .... day

CONFIDENCE FACTOR:
1 Probably reliable
2 Possibly reliable
3 Unknown

SAMPLE TYPES:

GRAB	Grab
CHIP	Chip
CHNL	Channel
BULK	Bulk Sample
ROCK	Rock Geochemistry
DIAD	Drill

NOTE For any given reserve category only two figures for any given year per ore zone may exist

Figure 7-2-3. MINFILE reserves.

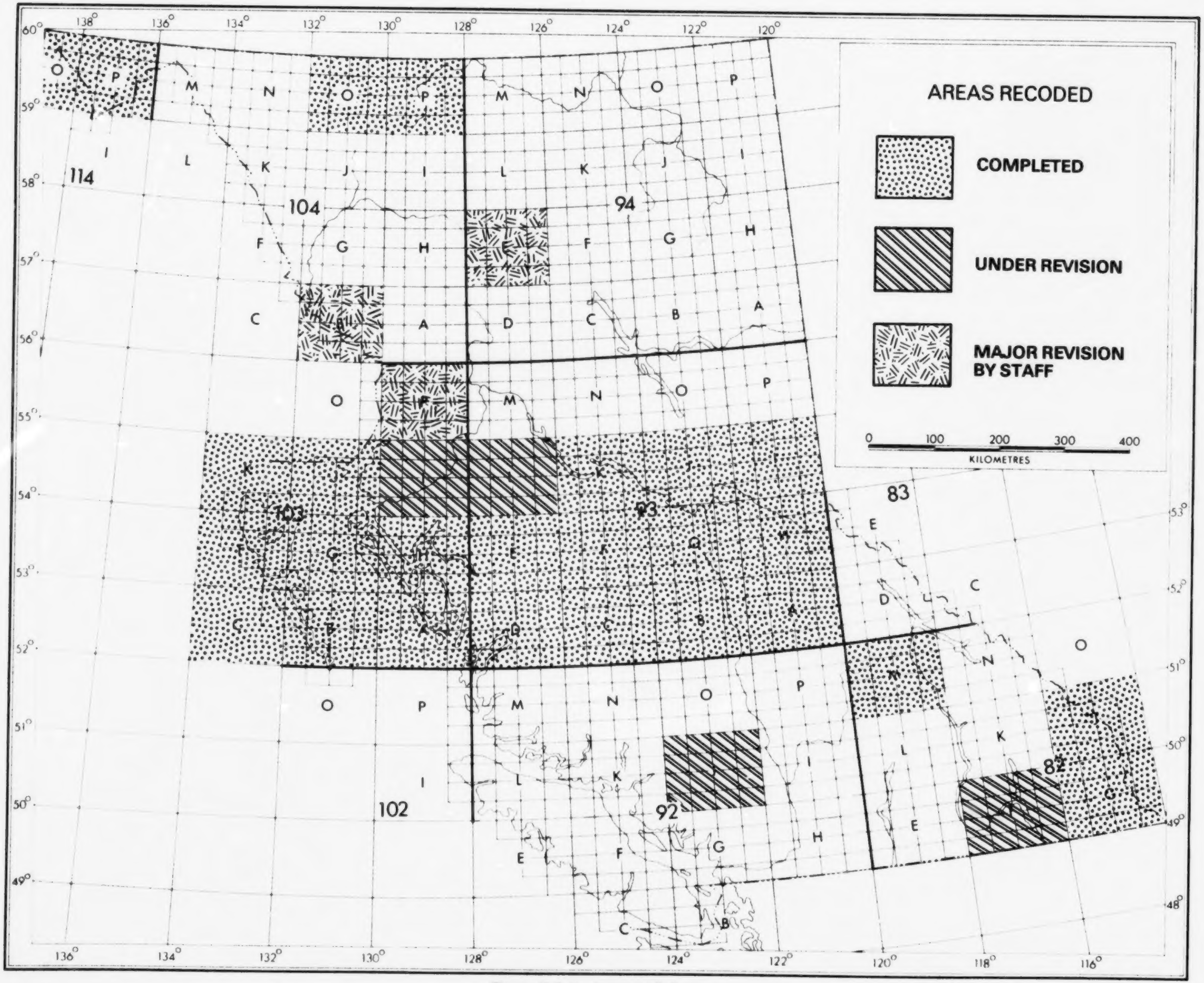

AREAS RECODED
COMPLETED
UNDER REVISION
MAJOR REVISION BY STAFF
0
100
200
300
400
KILOMETRES
114
104
94
103
93
83
102
92
82
60°
59°
58°
57°
56°
55°
54°
53°
52°
51°
50°
49°
48°
138°
136°
134°
132°
130°
128°
126°
124°
122°
120°
118°
116°

Figure 7-2-4. Areas coded.

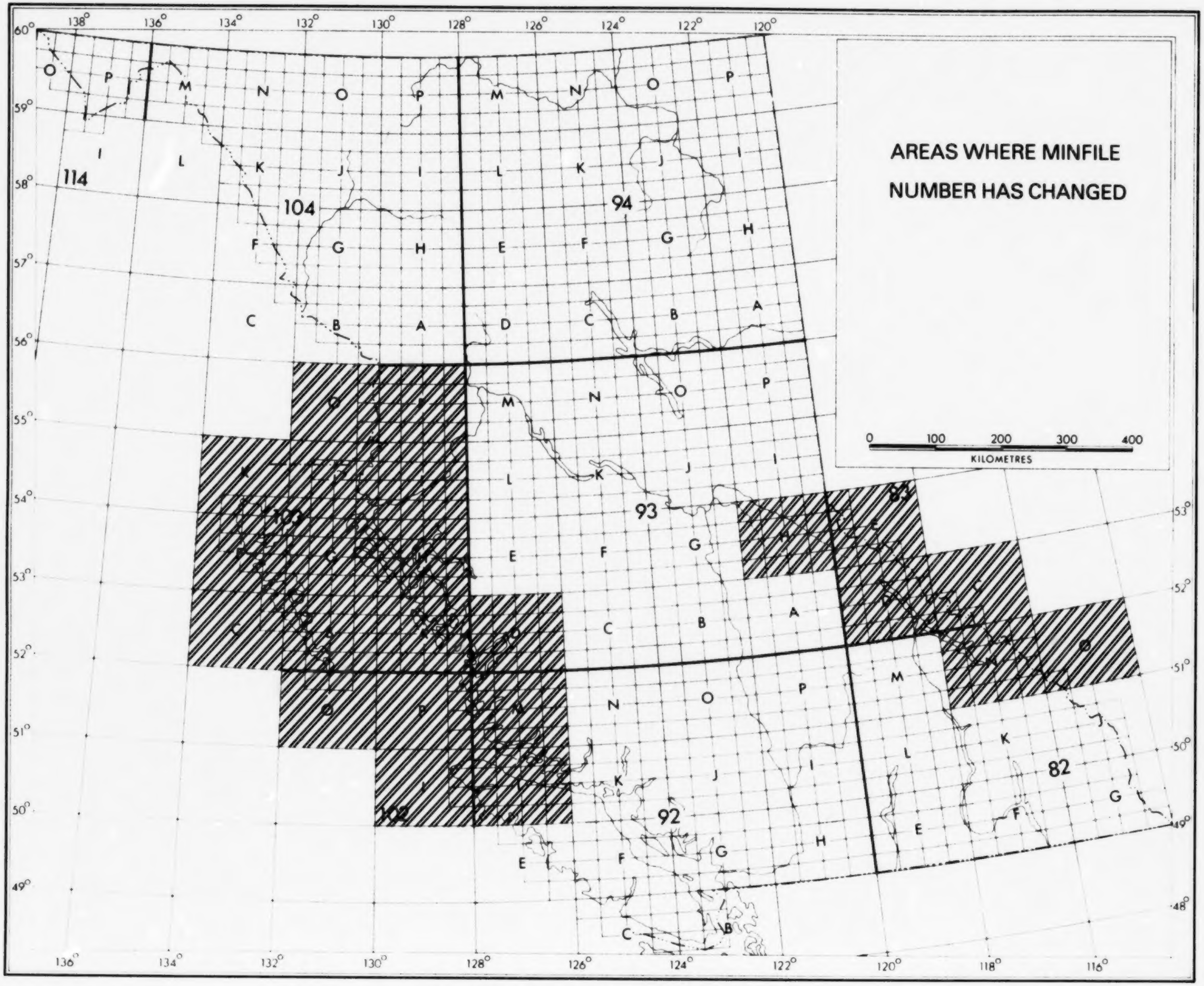

AREAS WHERE MINFILE NUMBER HAS CHANGED
0
100
200
300
400
KILOMETRES
114
104
94
93
92
82
83
103
102
60°
59°
58°
57°
56°
55°
54°
53°
52°
51°
50°
49°
48°
138°
136°
134°
132°
130°
128°
126°
124°
122°
120°
118°
116°

Figure 7-2-5. Change in MINFILE numbers.

one of the data maintenance screens that exist for any given occurrence. The user may combine any of these preprogrammed searches together, thus further refining the search

TABLE 7-2-1. PREPROGRAMMED SEARCHES

1. DEPOSIT NAME
2. STATUS
3. COMMODITY
4. MINERALOGY
5. AGE OF MINERALIZATION
6. DEPOSIT TYPE
7. GENETIC TYPE
8. HOST ROCK NAME
9. ROCK TYPE (LITHOLOGY)
10. STRATIGRAPHIC AGE
11. DEPOSITS WITH RESERVES
12. DEPOSITS WITH PRODUCTION

RECODING DEPOSITS

A team of contract geologists, aided by a research assistant, have been hired under the Canada/British Columbia Mineral Development Agreement to recode all the mineral occurrences in the province and to establish a hard-copy backup of all references associated with each occurrence. Coders receive technical guidance from staff and district geologists who have first-hand knowledge of the areas being recoded. Geological Survey Branch staff have also assisted in the collection of data and submitted revised descriptions of mineral occurrences that they have visited in the field.

As of the end of October 1986, over 2400 occurrences have been rewritten. This represents approximately 25 per cent of the existing occurrences in MINFILE. Of these 2400 occurrences approximately 25 per cent represent new mineral showings. Figure 7-2-4 shows the area of the province which has been reviewed by coders and staff. All the coal properties have been coded and are included in the totals.

In the old version of MINFILE, the deposit number was a sequential number based on the NTS system. Since one of the key elements in the redesign of MINFILE is for graphical representation, it was decided to change this key on certain map sheets. Figure 7-2-5 represents the areas effected by this change. For the most part they are the coastal regions around the Queen Charlotte Islands and the Rocky Mountain Foothills near the Alberta border.

Two open file publications have also been prepared in conjunction with the recoding. The first was released as Open File 1986-7 entitled "Occurrence and Distribution of Platinum-Group Elements in British Columbia", compiled by Jacqui Rublee. The other publication "Magnesite, Brucite and Hydromagnesite Occurrences in British Columbia", compiled by Brian Grant, is currently in preparation.

INFORMATION AVAILABLE

Upon the completion of redesigned MINFILE the following output reports will be available:

1. Paper (complete listings and descriptions of all occurrences).
2. Microfiche.
3. Computer tape (ASCII or EBCDIC).
4. MS-DOS diskettes (by map sheet area).

A number of conventional reports and indices will also be available. These include:

1. Alphabetic listing of deposits.
2. Commodity index.
3. Numeric index of MINFILE numbers.

Other selective searches and reports will be produced on a user-pay basis. SPECTRA, another CINCOM product, will be used to perform these *ad hoc* enquiries and to produce the reports.

Further information is available by telephone or mail from the authors at the address below:

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(604) 387-5666 or 387-1301

ACKNOWLEDGMENTS

The authors would like to acknowledge and thank Dr. Alan Campbell, Bill Green and Mit Tilkov for their assistance in providing direction for database design; Dr. Trygve Höy for his participation in the project team with the authors; the management committee (Dr. W.R. Smyth, Dr. W.J. McMillan, J.G. McArthur, K.G. Payne and A.B. Guilbault) for their guidance. Programming has been done by David Piesse of Anthony MacAuley Associates Ltd. and Gordon Lowe of SHL-Systemhouse. The coding is under the direction of the senior coder, Brian Grant. To date a total of six full/part-time geologists have also been hired to carry out this task. The present coding team consists of Brian Grant, Gary Foye, Larry Jones, Mary MacLean and Janet Fontaine. The authors would also like to thank Jacqui Rublee, John Bradford, Eileen Van der Flier-Keller, Garnet Dawson, Dani Alldrick, Tom Schroeter and all other staff members for their assistance in recoding occurrences in MINFILE. The recoding of deposits, the development of reference files and the compilation of commodity open files have been funded by the Canada/British Columbia Mineral Development Agreement.

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REPORT ON THE ESTABLISHMENT OF A COMPUTER FILE OF RADIOMETRIC DATES*

By A. Bentzen

INTRODUCTION

During the early part of 1986, a computer file was established consisting of the radiometric dates and ancillary data recorded in a manual file maintained by Dr. R.L. Armstrong of the Department of Geological Sciences, at The University of British Columbia. The great majority of dates are potassium-argon dates, with the remainder being rubidium-strontium, uranium-lead, and a few fission track dates. The number of dates is estimated to be approximately 3000.

DESCRIPTION OF MANUAL FILE

The manual file maintained by Dr. Armstrong comprises a set of forms in ring binders organized by 1:250 000-scale NTS designations. Three types of form make up the file, one for each of the three major classes of radiometric dates. The design of the forms was influenced by what is included in the United States Geological Survey Radiogenic Age Data Bank and the Geological Survey of Canada geochron file forms. The information recorded includes sample identification and geographic information, source material and analytical data, and the resultant dates and their interpretation. Also included are revised figures for dates to reflect, for example, revised decay constants. In order to obtain all the information available for one locale, it may be necessary to consult several forms since a single form only covers one dating method and dates may have been obtained on different occasions. As a consequence of having information spread over several forms a certain amount of information is duplicated, a fact which was taken into account in the design of the computer file.

LOGICAL STRUCTURE OF COMPUTER FILE

The computer file consists of a single ("flat") file comprising a number of logical records. Each record is based on the radiometric age dating effort of a particular researcher, at a unique location and on a single rock type. Each logical record consists of a collection of forms, and each form is a collection of data items. The file is line-oriented with each data item occuping a line; a field name occupies the left side of the line with a data field following on the right. Thus, at a lower level, the structure of the file is quite similar to that used in the NAMELIST concept in FORTRAN or the structure used on the distribution tapes of MINFILE.

In order to reduce redundancy, data items common to the three types of form have been "factored out". These items include identity of collector, rock type, latitude and longitude and description of location. The items that remain within each form are then specific to the kind of analysis involved.

ACCESS TO AND MODIFICATION OF COMPUTER FILE

Since the file might be put to different uses in different computing environments, it was felt that allowance for flexible access should be part of the design. The present design allows for accessing by a simple text editor, in fact that is in part how the file was created. A simple retrieval should not require a complicated program and with some modification, the file, may be used as an input file to some database management systems.

Modification of the file, such as alteration or the addition of new data, is not difficult. Addition of new data fields and forms is also possible, though such additions may affect how current programs access the file.

ACKNOWLEDGMENTS

I would like to thank Krista Scott for suggesting the project. The work was financially supported by the Ministry of Energy, Mines and Petroleum Resources through the Canada/British Columbia Mineral Development Agreement; by the Geological Survey of Canada; and by R.L. Armstrong, who also supplied the manual file.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

British Columbia Ministry of Energy, Mines and Petroleum Resources, Geological Fieldwork, 1986, Paper 1987-1.

GALENA LEAD ISOTOPE RESEARCH ON MINERAL DEPOSITS AT THE UNIVERSITY OF BRITISH COLUMBIA*

By C. I. Godwin and J. E. Gabites
Department of Geological Sciences
The University of British Columbia

Research by the Lead Isotope Research Group at The University of British Columbia, directed by the senior author in collaboration with R.L. Armstrong's Geochronology Laboratory, emphasizes the interpretation of galena lead isotopes to support decisions in mineral exploration, and contribute to the understanding of metallogeny in British Columbia. Lead isotopes from galena in mineral showings can be used to "fingerprint" mineral deposits to identify those with high potential; the isotopic signatures enhance the ability to classify deposits by age and genesis and focus exploration on high priority targets. The significance for increasing the effectiveness of mineral exploration is substantial and, in addition, our research should provide a sounder basis for the study of metallogeny as it relates to resource evaluation.

Our group is: (1) acquiring a library and computer-based file of galena samples from as many deposits as possible in the Canadian Cordillera, (2) developing case histories of exploration application, and (3) continuing research in models relevant to the study of metallogeny. Some details of these pursuits are outlined below.

Our library of galena currently consists of about 1400 samples. About 1000 of these are from 450 deposits in British Columbia. Most have been analysed at The University of British Columbia, at different times, with varying degrees of precision. These analyses, together with those available in the literature, have been entered into a computer-based "LEADTABLE". This (dBASEII) file contains: sample numbers; deposit name; details on the collector; location by latitude, longitude, NTS and MINFILE number; details on deposit type, age, host rock, and tectonic terrane; geological comments; details on the analyst and analytical quality; and galena lead isotope ratios with errors. Galena lead isotope data collected to date will be published as a British Columbia Ministry of Energy, Mines and Petroleum Resources paper in 1987. **Individuals with galena samples from deposits, particularly from recently discovered or remote showings, are urged to submit them to the authors**.

The study of galena lead isotope data is now commonly considered an essential element of detailed mapping of mineral deposits. In this report of activities, for example, galena lead isotopes are interpreted for the Stewart area (Alldrick *et al.*, 1987), and the Bend deposit in southeastern British Columbia (Reddy and Godwin, 1987). Goutier (1986) has recently completed a metallogenic study based on galena lead isotopes from 42 mineral occurrences on the Adams Plateau in south-central British Columbia. This study allows veins and volcanogenic deposits cogenetic with the Devono-Mississippian volcanics to be distinguished from all other types of occurrences. Goutier's work also illustrates that all occurrences on the plateau contain lead that is upper crustal in origin (this is unusual for lead from most volcanogenic deposits worldwide). This, together with Triassic apparent lead dates for deposits such as the Lucky Coon, tentatively indicate that part of the Eagle Bay Formation may be correlative with the Sicamous Formation and Slocan assemblage, rather than the current Cambrian interpretation (Schiarizza and Preto, 1985).

Support from the British Columbia Ministry of Energy, Mines and Petroleum Resources, the Canada/British Columbia Mineral Development Agreement (MDA) and the British Columbia Science Council is gratefully acknowledged. Many geologists from the Ministry have contributed galena specimens and have participated in studies that are ongoing or reported here.

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* This project is a contribution to the Canada/British Columbia Mineral Development Agreement.

University Research

UNIVERSITY RESEARCH IN BRITISH COLUMBIA

INTRODUCTION

This listing of current theses on the geology and mineral deposits of British Columbia will be an annual feature in this publication. It is included to bring these important contributions to the attention of explorationists, who otherwise may be unaware of them.

Earth Science Departments are encouraged to send a current listing to the Editor, Geological Fieldwork and Current Research, no later than October 31 of each year.

TABLE 8-1-1. UNIVERSITY RESEARCH IN BRITISH COLUMBIA

AUTHOR	TITLE
THE UNIVERSITY OF BRITISH COLUMBIA, 1985	
Andrew, K.P.E.	Fluid Inclusion and Chemical Studies of Gold-quartz Veins in the Atlin Camp, Northwestern British Columbia. (B.Sc.)
Archambault, M.	Geology and Mineralography of the Silver Creek Deposit, Midway Property, North-central British Columbia. (M.Sc.)
Armstrong, J.E.	A Slope Design for Cominco's Valley Copper Mine Including a Review of the Major Factors Influencing the Wallrock Stability. (B.A.Sc.)
Arthur, A.J.	Biostratigraphy of the Lower to Middle Jurassic Sediments, Ashcroft Area, South Central British Columbia. (B.Sc.)
Bean, S.M.	Slope Stability of the Dusty Mac Pit, Okanagan Falls, South Central British Columbia. (B.A.Sc.)
Benitez, J.M.	A Comparison of the Design Parameters Obtained Using Three Different Methods of Slope Design for Open Pit Mines. (B.A.Sc.)
Bishop, S.T.	The Petrology of the Flourmill Volcanic Centre in the Clearwater-Wells Gray Area, East-central British Columbia. (B.Sc.)
Bradford, J.A.	Geology and Alteration in the Taseko River Area, Southwestern British Columbia. (B.Sc.)
Brox, D.R.	Spatial Variability of Hydrogeologic Parameters in the Upper Zone of the Quadra Sand, at Towers Beach, Point Grey, British Columbia. (B.A.Sc.)
Carter, E.S.	Early and Middle Jurassic Radiolarian Biostratigraphy, Queen Charlotte Islands, British Columbia. (M.Sc.)
Davies, M.P.	Application of the Piezometer Cone Penetration Test to Slope Stability Evaluation Focus: Haney Slide. (B.A.Sc.)
Day, S.	A Petrographic and Geochemical Comparison of Massive Sulphide Boulders in Outwash from East Arm Glacier, St. Elias Mountains, British Columbia, with the Windy-Craggy Deposit. (B.Sc.)
Duggan, D.M.	Development-related Erosion of the Intertidal Area, Roberts Bank on the Fraser River Delta, British Columbia. (B.A.Sc.)
Elsby, D.C.	Structure and Deformation Across the Quesnellia-Omineca Terrane Boundary, Mt. Perseus Area, East-central British Columbia. (M.Sc.)
Erdman, L.R.	Chemistry of Neogene Basalts of British Columbia and the Adjacent Pacific Ocean Floor: A Test of Tectonic Discrimination Diagrams. (M.Sc.)
Fillipone, J.A.	Structure and Metamorphism at the Western Margin of the Omineca Belt near Boss Mountain, East Central British Columbia. (M.Sc.)
Gabites, J.E.	Geology and Geochronometry of the Cogburn Creek-Settler Creek Area, Northeast of Harrison Lake, British Columbia. (M.Sc.)
Getsinger, J.S.	Geology of the Three Ladies Mountain/Mount Stevenson Area, Quesnel Highland, British Columbia. (Ph.D.)
Guyan, P.G.A.	Petroleum Geology of the Mississippian Strata, Desan Region of Northeastern British Columbia. (B.Sc.)
Haering, L.J.	Mineralogical and Chemical Variations in Basaltic Lava Flows from the Garibaldi Area, Southwest British Columbia: Implications for Conductive and Convective Heat Loss. (B.A.Sc.)
Hewgill, W.V.	Geochronology and Rare Earth Element Geochemistry of a Metasomatic Albitite in Northwestern British Columbia. (B.Sc.)
Howie, P.	The Geology of the Helga-FRS Copper Prospect, Mesachi Lake Area, Vancouver Island, British Columbia. (B.Sc.)
Humer, D.S.	The Hydrocarbon Potential of the Mississippian Debolt Formation in Northeastern British Columbia. (B.Sc.)
Knight, J.B.	A Microprobe Study of Placer Gold and its Origin in the Lower Fraser River Drainage Basin, British Columbia. (M.Sc.)
Konkin, K.J.	Geology and Mineralogy of the Bismark-Gold Cure Silver-lead-zinc Veins, Kaslo Area, Southeastern British Columbia. (B.Sc.)
Laidlaw, J.S.	A Geologic and Slope Stability Investigation of a Section of Highway 101 near Ruby Lake, British Columbia. (B.A.Sc.)
Lorenzetti, G.M.	A Diagenetic Interpretation and Provenance Study of the "Jackson", "Currier", "McEvoy", and "Devil's Claw" Units of the Groundhog Coalfield, Bowser Basin, British Columbia. (B.Sc.)
Losch, A.H.A.	A Stability Analysis for the Proposed Footwall Slope Portion of the Kutcho Creek Massive Sulphide Deposit, in Northern British Columbia. (B.A.Sc.)
Lueck, B.A.	Geology of Carbonatized Fault Zones on the Anna Claims and Their Relationship to Gold Deposits, Atlin, British Columbia. (B.Sc.)
McIntyre, M.S.L.	Erosion, Due to the Slabbing Process, of Quadra Sand at the Point Grey Cliffs, Vancouver, British Columbia. (B.A.Sc.)
Marsden, H.W.	Some Aspects of the Geology, Mineralization and Wallrock Alteration of the Nadina Zn-Cu-Pb-Ag-Au Vein Deposit, North Central British Columbia. (B.Sc.)

AUTHOR	TITLE
Matysek, P.F.	An Evaluation of Regional Stream Sediment Data by Advanced Statistical Procedures. (M.Sc.)
Moffatt, I.W.	The Nature and Timing of Deformation Events and Organic and Inorganic Metamorphism in the Northern Groundhog Coalfield: Implications for the Tectonic History of the Bowser Basin. (Ph.D.)
Montgomery, J.R.	Structural Relations of the Southern Quesnel Lake Gneiss, Isosceles Mountain Area, Southwest Cariboo Mountains, British Columbia. (M.Sc.)
Newcomen, H.W.	Engineering Geology and Geotechnical Assessment of the Southeast Wall Slope Failure at Highmont Mine, British Columbia. (B.A.Sc.)
Newton, D.C.	A Study of Carbonate Alteration of Serpentinites Around Au and Ag Bearing Quartz Veins in the Atlin Camp, British Columbia. (B.Sc.)
Noble, P.R.	Analysis of Responses of a Downhole Geophysical Tool (The Sidewall Densilog) for Purposes of Correlating Geology in the Lower Cretaceous Shaftesbury Formation, Northeastern British Columbia. (B.A.Sc.)
O'Brien, J.A.	Biostratigraphy of the Lower Jurassic (Sinemurian) Tyaughton Group, Taseko Lakes Map Area, South Central British Columbia. (B.Sc.)
Ochs, E.P.P.	Wall Rock Alteration and Vein Mineralogy of the Hank Epithermal Gold Prospect, Northwestern British Columbia. (B.Sc.)
Parkinson, D.L.	U-Pb Geochronometry and Regional Geology of the Southern Okanagan Valley, British Columbia: The Western Boundary of a Metamorphic Core Complex. (M.Sc.)
Sedun, L.T.	The Geology and Mineralization of the Mad Claim, Lillooet Mining Division. (B.Sc.)
Thomson, R.C.	Lower to Middle Jurassic (Pliensbachian to Bajocian) Stratigraphy and Pliensbachian Ammonite Fauna of the Northern Spatsizi Area, North Central British Columbia. (M.Sc.)
Uyeda, E.Y.	Quantitative Analysis of Debris Torrent Magnitudes for Alberta, Newman, and Sclufield Creeks, Highway 99, Howe Sound, British Columbia. (B.A.Sc.)
Westervelt, L.A.	A Computer Facilitated Statistical Analysis of Three Soil Geochemical Grids in the Nakusp Area, South Central British Columbia. (B.A.Sc.)
Wilson, R.G.	A Stability Analysis of a Glaciolacustrine Silt Bluff Slope, Kamloops, British Columbia. (B.A.Sc.)

THE UNIVERSITY OF BRITISH COLUMBIA, 1986

Bartle, H.T.	Computer Applications to Coal Reserve Estimation. (B.A.Sc.)
Carye, J.A.	Structural Geology of Part of the Crooked Lake Area, Quesnel Highlands, British Columbia. (M.Sc.)
Collett, T.F.W.	An Estimation of the Extent of Liquefaction and Associated Damage Potential in Richmond, Southwest British Columbia. (B.A.Sc.)
Dalton, R.D.	Application of a New Finite Element Program to the Analysis of Groundwater Flow in Downie Slide, British Columbia. (B.A.Sc.)
Dom, K.	The Beaufort Range Fault Zone in the Alberni Area. (B.Sc.)
Ehling, M.L.	Shallow Reflection Seismic Survey. (B.A.Sc.)
Fields, M.	Geology of the Still's Ridge Barite, Zinc, Copper, Silver Prospect, St. Elias Mountains, Northwestern British Columbia. (B.Sc.)
Forster, P.J.	Lower Permian Conodont Biostratigraphy of the Harper Ranch Group, near Kamloops, South Central British Columbia. (B.Sc.)
Gorzyniski, G.A.	Geology and Lithogeochemistry of the Cirque Stratiform Sediment-hosted Ba-Zn-Pb-Ag Deposit, Northeastern British Columbia. (M.A.Sc.)
Grainger, W.W.	A Sensitivity Analysis of the Groundwater Flow System at Burns Bog, Delta, British Columbia, Using A Finite Element Computer Model. (B.Sc.)
Green, K.C.	Petrology of the Volcanic Rocks of the Karmutsen Formation, Ikeda Cove, Queen Charlotte Islands, British Columbia. (B.Sc.)
Grill, E.C.	Petrology of the Thom Claim, South Central British Columbia. (B.Sc.)
Gunning, M.H.	Late Triassic to Middle Jurassic (Norian to Oxfordian) Volcanic and Sedimentary Stratigraphy and Structure in the Southeastern Part of the Iskut River Map Sheet, North-central British Columbia. (B.Sc.)
Ijewliw, O.J.	Comparative Mineralogy of Three Ultramafic Breccia Diatremes in Southeastern British Columbia — Cross, Blackfoot and HP. (B.Sc.)
Jung, A.	Geochronometry and Geochemistry of the Thuya, Takomkane, Raft, and Baldy Batholiths, West of the Shuswap Metamorphic Complex, South-central British Columbia. (B.Sc.)
Koecher, T.	Preliminary Site Investigation of the Peace River Bridge Crossing at Clayhurst, British Columbia. (B.A.Sc.)
Lisowski, M.	Geodetic Strain Measurements in Central Vancouver Island. (M.Sc.)
Logan, J.M.	Geochemical Constraints on the Genesis of Ag-Pb and Zn Deposits, Sandon, British Columbia. (M.Sc.)
MacLean, M.E.	Depositional Environment and Provenance of the Pasayten Group, Treasure Mountain, Southeastern British Columbia. (B.Sc.)
McQuarrie, E.J.	1985 Summer Geotechnical Investigation Data Report for Gulf Canada's Mount Klappan Coal Project. (B.A.Sc.)
Miller, M.	A Study of the Lower Cretaceous Bluesky Formation in the Ladyfern Area of Northeastern British Columbia. (B.A.Sc.)

AUTHOR	TITLE
Reddy, D.G.	Geology of the Bend Zn-Pb-Ag Sediment Hosted, Massive Sulphide Prospect, Southeastern British Columbia. (B.Sc.)
Reed, M.T.	The Petrography and the Ore Microscopy of Three Zones on the Red Tusk Property, Southwestern British Columbia. (B.Sc.)
Reschke, A.E.	Proposed Tunnel Design to Realign the Squamish Highway Between Magnesia and M Creeks. (B.A.Sc.)
Robertson, M.D.	Principles and Parameters for the Design of a Portable Shear Wave Source. (B.A.Sc.)
Robinson, C.	Geology of the Ford Property, Adams Plateau, South Central British Columbia. (B.Sc.)
Sketchley, D.A.	The Nature of Carbonate Alteration in Basalt at Erickson Gold Mine, Cassiar, North-central British Columbia. (M.Sc.)
Smith, B.W.	The Belloy Formation, Eagle Field, Northeast British Columbia: A Continuity Study and Waterflood Design. (B.A.Sc.)
Thiersch, P.	The Geology of the Wolf Silver Prospect, Upper Kitsault Valley, British Columbia. (B.Sc.)
Thompson, D.A.	A Mineralogical Analysis of the "Bentonite" in the Mount Klappan Area of Northwestern British Columbia. (B.Sc.)
Thorkelson, D.J.	Volcanic Stratigraphy and Petrology of the Mid-Cretaceous Spences Bridge Group near Kingsvale, Southwestern British Columbia. (M.Sc.)
West, J.L.	A Proposal for a Geotechnical Data Base for the Lower Mainland Area, British Columbia. (B.A.Sc.)
Woodward, P.C.	Engineering Study to Determine a Design for a Proposed Retaining Wall and Waterfront Walkway in New Westminster, British Columbia. (B.A.Sc.)

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Gentzis, T.	Organic Petrology and Depositional Environment of the Hat Creek, No. 2 Coal Deposit, British Columbia, Canada.
MacDonald, D.E.	Geology and Resource Potential of Phosphates in Alberta and Portions of Southeastern British Columbia.

UNIVERSITY OF ALBERTA, 1986

Brearley, M.	Ultramafic Xenoliths from British Columbia: Petrological and Dissolution Studies.
Ghosh, D.K.	Geochemistry of the Nelson-Rossland Area, Southern British Columbia.
Smith, A.D.	Isotopic and Geochemical Studies of Terrane I, South-central B.C. (Ph.D.)
Wolberg, A.C.	Sedimentology of the Lower Cambrian Gog Group, British Columbia: An Early Cambrian Tidal Deposit.

UNIVERSITY OF ARIZONA

Harms, T.A.	Structural and Tectonic Analysis of the Sylvester Allochthon, Northern British Columbia: Implications for Paleogeography and Accretion. (1986, Ph.D.)

BROCK UNIVERSITY

Wassenaar, L.I.	Geochemical and Paleoecological Investigation of Marine Molluscs of Late Pleistocene Submergences, Ontario, Quebec and British Columbia. (1986, M.Sc.)

BRYN MAWR COLLEGE

O'Leary, E.F.	An Overview of the Occurrence of Granitic Dykes in the Northern Coast Mountains, B.C. (1985, B.S.)

UNIVERSITY OF CALGARY

Corbett, C.R.R.	The Campion Lake Fault: A Tertiary, East-side-down Normal Fault in Southeastern British Columbia. (1985, M.Sc.)

CARLETON UNIVERSITY

Murphy, D.C.	Stratigraphy and Structure of the East-central Cariboo Mountains, British Columbia and Implications for the Geological Evolution of the Southeastern Canadian Cordillera. (1985, Ph.D.)
Carr, S.D.	The Valkyr Shear Zone and the Slocan Lake Fault: Eocene Structures that Bound the Valhalla Complex, Southeastern British Columbia. (1986, M.Sc.)

OREGON STATE UNIVERSITY

Price, G.	Geology and Mineralization, Taylor-Windfall Gold Prospect, British Columbia, Canada. (1986, M.S.)

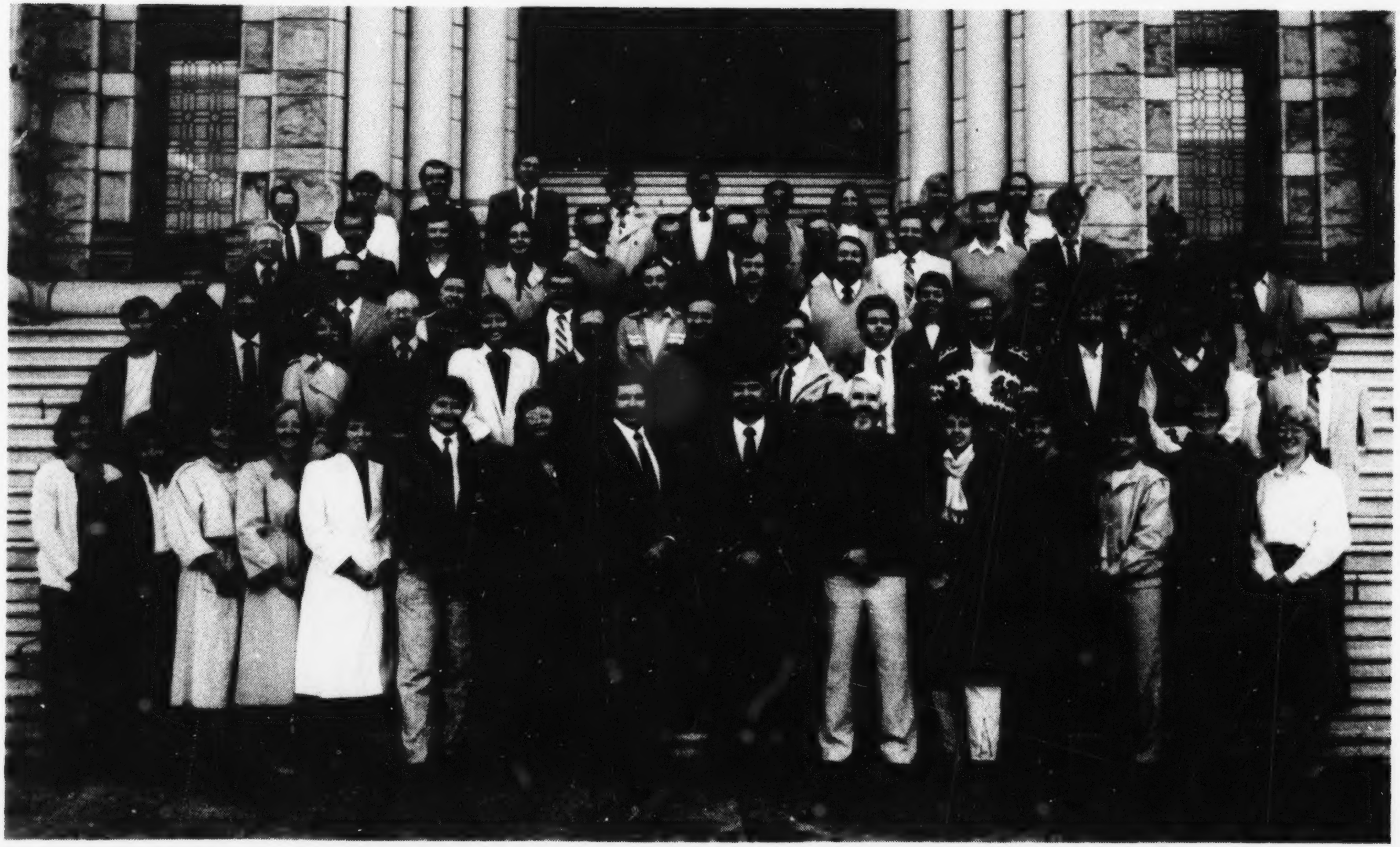
PRINCETON UNIVERSITY

Sisson, V.B.	Contact Metamorphism and Fluid Evolution Associated with the Intrusion of the Ponder Pluton, Coast Plutonic Complex, British Columbia, Canada. (1985, Ph.D.)

QUEEN'S UNIVERSITY

Evenchick, C.A.	Stratigraphy, Metamorphism, Structure, and their Tectonic Implications in the Sifton and Deserters Ranges, Cassiar and Northern Rocky Mountains, Northern British Columbia. (1985, Ph.D.)
Heather K.B.	The Aylwin Creek Gold-copper-silver Deposit, Southeastern British Columbia. (1985, M.Sc.)

AUTHOR	TITLE
L'UNIVERSITÉ DES SCIENCES ET TECHNIQUES DE LILLE	
Blaise, B.	Sédimentation et Paléoenvironnements Plio-quaternaires sur la Bordure Nord-Est de l'Ocean Pacifique. (1985, Ph.D.)
SIMON FRASER UNIVERSITY	
Saunders, I.R.	Late Quaternary Geology and Geomorphology of the Chilliwack River Valley, British Columbia. (1985, M.Sc.)
UNIVERSITY OF TORONTO	
Hannington, M.D.	Geology, Mineralogy and Geochemistry of a Silica-sulfate-sulfide Deposit, Axial Seamount, Northeastern Pacific Ocean. (1986)
WESTERN WASHINGTON UNIVERSITY	
Dussell, E.	Listwanites and their Relationship to Gold Mineralization at Erickson Mine, British Columbia (1986, M.S.)
UNIVERSITY OF WASHINGTON	
Haugerud, R.A.	Geology of the Hozameen Group and the Ross Lake Shear Zone, Maselpanik Area, North Cascades, Southwest British Columbia. (1985, Ph.D.)
Garver, J.I.	Sedimentology and Stratigraphy of the Lower Cretaceous Taylor Creek Group, Tyaughton Creek Area.
Kveton, K.J.	Structure and Petrology of Pre-Cretaceous Rocks on Saltspring Island, Portland Island and Moresby Island.
Miller, M.G.	Kinematic History of the Yalakom Fault, near the Junction of the Bridge River and Fraser River.
Rusmore, M.E.	Geology and Tectonic Significance of the Upper Triassic Cadwallader Group and its Bounding Faults, Southwestern British Columbia. (1985, Ph.D.)
Umhoefer, P.J.	Structure, Stratigraphy, and Sedimentology of the Triassic-Jurassic Tyaughton and Relay Mountain Groups, Tyaughton Creek Area.
UNIVERSITY OF WESTERN ONTARIO	
Parkin, G.W.	Sedimentology of a Pleistocene Glacigenic Diamicton Sequence near Campbell River, Vancouver Island, British Columbia. (1986, M.Sc.)



Left to right: Front row — Mary Anne Bloodgood, Norma Chan, Laura de Groot, Cindy Borsholm, Bev Gordon, Paul Matysek, Candace Kenyon, Dani Alldrick, Ron Smyth, John Armitage, Janet Fontaine, Ginette Carter, Jackie Lawson, Barbara Mordaunt, Kim Green

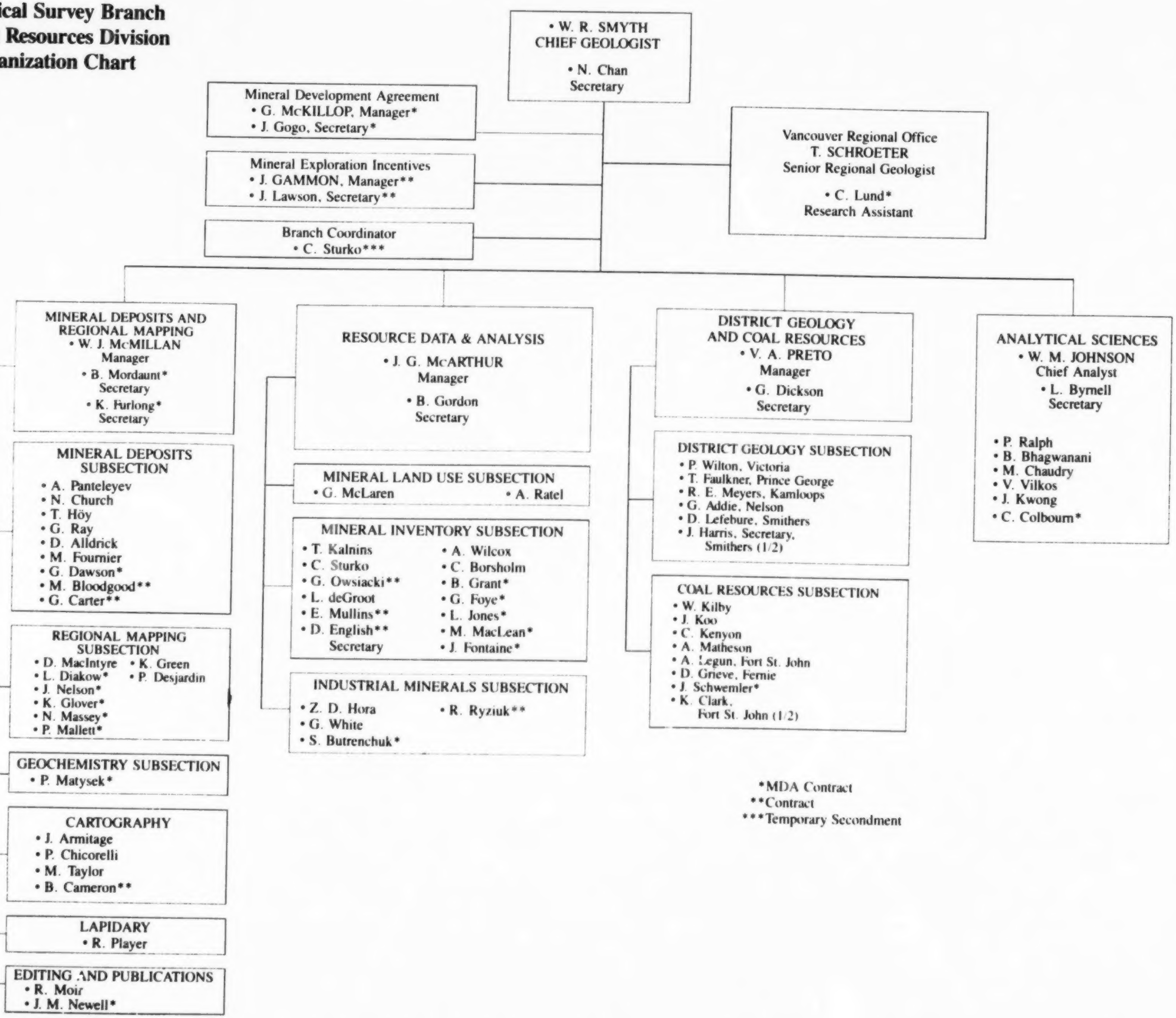
Second row — Paul Ralph, Ward Kilby, Phyllis Mallett, Neil Church, Claudia Sturko, Don MacIntyre, Danny Hora, Brian Grant, Larry Jones, Paul Wilton, Keith Glover, Bish Bhagwanani, Jahak Koo

Third row — Garnet Dawson, Ted Faulkner, Dick Player, Gary White, Nick Massey, Mike Fournier, Alan Wilcox, Joanne Schwemler, Jeanette Gogo, Eileen Mullins, Lynn Byrnell

Fourth row — Bill McMillan, Graeme McLaren, Greg McKillop, Ann Râtel, Wes Johnson, Stephen Butrenchuk, Andre Panteleyev, Vic Preto, Gib McArthur, Gary Foye, David Grieve, Trygve Höy, Mac Chaudhry

Fifth row — George Addie, Geri Dickson, Andrew Legun, David Lefebure, Talis Kalnins, Alex Matheson, John Kwong, JoAnne Nelson, Kay Furlong, Pierno Chicorelli

Geological Survey Branch
Mineral Resources Division
Organization Chart



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